MOUSS Protocol for the Pacific Islands Fisheries Science Center

Dianna R. Miller-Greene, Ruhul Amin, Jeremy C. Taylor, and Jacob Asher

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Marine Fisheries Service
Pacific Islands Fisheries Science Center

NOAA Technical Memorandum NMFS-PIFSC-102
https://doi.org/10.25923/7q3t-yk14

May 2020

MOUSS Protocol for the Pacific Islands Fisheries Science Center

Dianna R. Miller-Greene[1], Ruhul Amin[2], Jeremy C. Taylor[1], and Jacob Asher[1]

[1]Joint Institute for Marine and Atmospheric Research
University of Hawaii
1000 Pope Road
Honolulu, Hawaii 96822

[2]Pacific Islands Fisheries Science Center
National Marine Fisheries Service
1845 Wasp Boulevard
Honolulu, HI 96818

NOAA Technical Memorandum NMFS-PIFSC-102

May 2020

U.S. Department of Commerce
Wilbur L. Ross, Jr., Secretary

National Oceanic and Atmospheric Administration
Neil A. Jacobs, Ph.D., Acting NOAA Administrator

National Marine Fisheries Service
Chris Oliver, Assistant Administrator for Fisheries

Recommended citation

Miller-Greene DR, Amin R, Taylor JC, Asher J. 2020. MOUSS protocol for the Pacific Islands Fisheries Science Center. U.S. Dept. of Commerce. NOAA Technical Memorandum. NMFS-PIFSC-102, 96 p. doi:10.25923/7q3t-yk14

Copies of this report are available from

Science Operations Division
Pacific Islands Fisheries Science Center
National Marine Fisheries Service
National Oceanic and Atmospheric Administration
1845 Wasp Boulevard, Building #176
Honolulu, Hawaii 96818

Or online at

https://repository.library.noaa.gov/

Cover: Photo courtesy of Dianna Miller-Greene.

Table of Contents

List of Tables

List of Figures

Executive Summary

The Modular Optical Underwater Survey System (MOUSS) is an optical stereo-camera system designed by the Pacific Islands Fisheries Science Center (PIFSC) for *in situ* visual sampling of fish assemblages. The system is rated to 500 meters (m) and can effectively identify fish at depths of up to 250 m in Hawaiian waters using only ambient light (up to 300 m on a clear day around noon). Beginning in 2013, the system was tested and deployed in the main Hawaiian Islands (MHI), the Caribbean, the Gulf of Mexico, and off the coast of California. Currently, the MOUSS remains an integral tool for fishery-independent surveys of the commercially and culturally important Hawaiian "Deep 7" bottomfish, which includes a managed complex of six deep-water snapper and one grouper species. This document was generated to support the fisheries optical stereo-video data community with protocols for camera deployment and recovery, data processing, and annotation of in situ stereo-video data.

Section 1. Introduction – Provides an overview of stereo-video imaging for fisheries research, background information about the Hawaiian bottomfish fishery and rationale for development of the MOUSS to generate size-structured fish abundance estimates for improved bottomfish stock assessments. This section also discusses the MOUSS's predecessor, known as the Bottom Camera Bait Station (BotCam), and MOUSS configuration and limitations.

Section 2. MOUSS Components and Electronic Accessories – Describes the MOUSS hardware, including the digital video recorder (DVR), cameras, battery, and frame, as well as electronic accessories used during MOUSS surveys.

Section 3. MOUSS Calibration – This section discusses the MOUSS camera calibration protocol using a "calibration cube" method. All MOUSS cameras are calibrated before and after each survey to ensure accurate measurement of target bottomfish species. **Appendix A** provides step-by-step instructions for the MOUSS calibration using SeaGIS CAL software.

Section 4. Sampling Strategies, Field Deployment and Recovery – The MOUSS is primarily deployed from small boats while a portion of deployments are conducted from larger research vessels including NOAA Ship *Oscar Elton Sette*. This section describes the MOUSS survey sampling design, deployment and recovery procedures for a small boat platform, and modifications for deployment from a larger research vessel. **Appendix B** provides step-by-step instructions for MOUSS deployment and recovery from a small boat.

Section 5. The MOUSS Data: Structure, Processing, and Video Annotation – The MOUSS digital images are downloaded daily following field operations and images are converted to videos. Videos are later reviewed and annotated to generate bottomfish data. This section describes the MOUSS filename structure, InPort metadata structure, data download and processing, and video annotation procedures. **Appendix C** provides step-by-step data download and processing instructions in Linux Ubuntu environment. **Appendix D** provides Perl scripts for automated video creation. **Appendix E** provides step-by-step stereo-video annotation instructions using SeaGIS EventMeasure™ software.

Section 6. Integration of New Technologies – The modular design of the MOUSS allows for efficient and cost-effective use with complementary new technologies and variable deployment

platforms. Since its inception, a variety of technologies have been paired with the MOUSS package to complement ongoing bottomfish surveys, and PIFSC's research and development (R&D) work. This section provides an overview of some of these technologies.

Acronyms Key

2-D –two-dimensional
3-D –three-dimensional
AC –alternating current
Ah –ampere hour
AUV –autonomous underwater vehicle
AVI –audio video interleave
BFISH –Bottomfish Fishery-Independent Survey in Hawaii
BotCam –Bottom Camera Bait Station
BRFA –bottomfish restricted fishing area
CCD –charge coupled device
CPU –central processing units
CTD –conductivity, temperature, and depth
DAR –Division of Aquatic Resources
DIDSON –dual-frequency identification sonar
DVR –digital video recorder
FOV –field of view
fps –frames per second
HD –hard drive
ID –identify/identification
LED –light emitting diode
MaxN –maximum number (of fish observed)
MHI –main Hawaiian Islands
MIL –Marine Instrumentation Lab
MOUSS –Modular Optical Underwater Survey System
NiMH –nickel metal hydride
NMFS –National Marine Fisheries Service
NOAA –National Oceanic and Atmospheric Administration
OA –Ossolinski Actuator
PIFSC –Pacific Islands Fisheries Science Center
PoE –power over Ethernet
R&D –research and development
ROS –Remote Ocean Systems
ROV –remotely operated videos
SGI –silicon graphics image
SSD –solid state hard drive
TDR –temperature depth recorder
TOFA –time of first arrival
UTC –universal time coordinated
USB –universal serial bus
USD –United States dollars
V –volt
VDC –volts of direct current
W –watt

1. Introduction

1.1 Background

The National Oceanic and Atmospheric Administration (NOAA) Fisheries' stock assessments remain a key component of proper federal resource management, as mandated under the Magnuson-Stevens Fishery Conservation and Management Act (Magnuson-Stevens Fishery Conservation and Management Act 2007). Accurate stock assessments rely on information on fish biology (i.e., life history data), catch rates, and fish abundance estimates. Historically, fish abundance data have been derived from fishery-dependent data, such as reported catch and fishing effort, but these estimates can be biased by factors including gear type and market prices (Richards et al. 2016). To avoid such biases, direct monitoring of fish populations using fishery-independent methods are used to estimate abundance data for key fish stocks (Cappo et al. 2006, Murphy and Jenkins 2010). Finally, fishery-independent survey designs are less affected by market demand, fuel prices, and technological advances in fishing methods, which influence commercial catch and effort data, but remain unrelated to stock status.

Underwater camera systems have a long history of use in fisheries research. Over the past decade, rapid and significant advances in the application of in situ camera technologies have been used to provide non-extractive, fishery-independent surveys without some of the limitations inherent to other survey methods (Langlois et al. 2012, Mallet and Pelletier 2014). These systems can generate species metrics (including abundance and size), can be used to study spatial and temporal trends, examine native behavioral patterns, and habitat use (Shortis et al. 2013). Following video collection, fish species are identified, counted and annotated to the lowest possible taxonomic level, and measured, reducing the logistical constraints and costs of hosting taxonomic experts in the field. Multiple specialists can review, annotate, and quality control video footage, thus reducing inter-observer error, facilitating transfer of knowledge between analysts, and allowing review of anomalous records. Finally, video data can be archived for future analyses, and used for public education and outreach.

1.2 Hawaiian Bottomfish and Management

The Hawaiian deep-slope snapper fishery has a long history of cultural importance, with traditional hook-and-line fishing dating back centuries (Haight et al. 1993). Currently, the Hawaiian deep-slope "bottomfish" fishery preferentially targets six (6) species of snapper: ōpakapaka (*Pristipomoides filamentosus*), kalekale (*P. sieboldii*), gindai (*P. zonatus*), ehu (*Etelis carbunculus*), onaga (*E. coruscans*), lehi (*Aphareus rutilans*), and one species of grouper, hapuʻupuʻu (*Hyporthodus quernus*; Figure 1.1). These commercially important species are collectively managed as the Hawaiian "Deep 7" stock (Western Pacific Regional Fishery Management Council 2010). The fishery includes a mix of participants, including subsistence, recreational, and commercial fishermen, with an annual catch of 218,035 lb of Deep 7 species sold at an average adjusted price of $7.82 USD/lb in 2018 (Western Pacific Regional Fishery Management Council 2019).

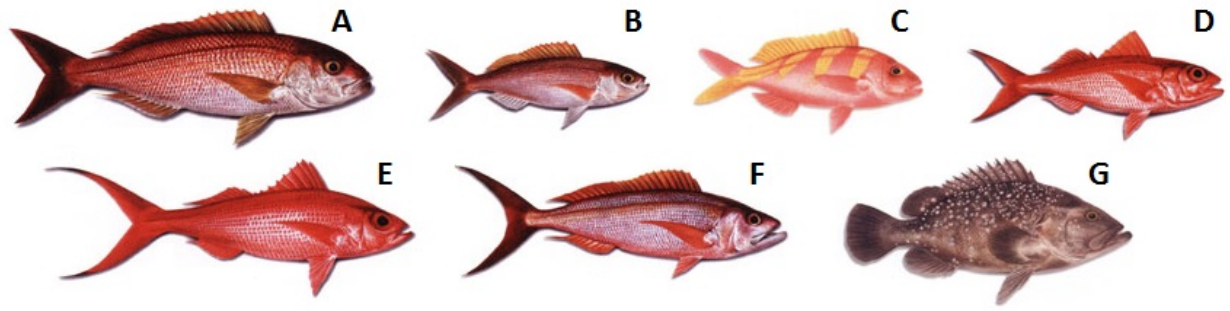

Figure 1.1 The Deep 7 bottomfish: (A) *Pristipomoides filamentosus*, (B) *Pristipomoides sieboldii*, (C) *Pristipomoides zonatus*, (D) *Etelis carbunculus*, (E) *Etelis coruscans*, (F) *Aphareus rutilans*, and (G) *Hyporthodus quernus*.

Credit: Artwork by Les Hata, State of Hawaii Division of Aquatic Resources.

The Deep 7 bottomfish prefer hard-bottom, high-slope habitat types, which include deep sloping ridges and seamounts between 100 m and 400 m (Kelley et al. 2006, Misa et al. 2013, Oyafuso et al. 2017). Most bottomfish species reach maturity in several years but some eteline snappers live up to 35 years, which indicates low rates of natural mortality and an inherent susceptibility to overfishing (Haight et al. 1993, Andrews et al. 2012).

Throughout the 1990s and early 2000s, excessive fishing pressure in the MHI resulted in the overfishing of two bottomfish species, onaga (*E. coruscans*) and ōpakapaka (*P. filamentosus*) (Moffitt et al. 2006, Brodziak et al. 2011). As a result, the Magnuson-Stevens Fishery Conservation and Management Act of 2007 mandates corrective measures to restore overfished stocks to healthy levels (i.e., abundance that would allow for long-term maximum sustainable yields) within a 10-year time period. In response, the State of Hawaii Division of Aquatic Resources (DAR) established bottomfish restricted fishing areas (BRFAs) in 1998, prohibiting bottomfishing within their borders (State of Hawaii 2010). These restrictions were revised in 2007 following the improved mapping of the hard-bottom habitats preferred by most bottomfish species (Parke 2007), and recently reduced in number from 12 to 8 in 2019 (Figure 1.2).

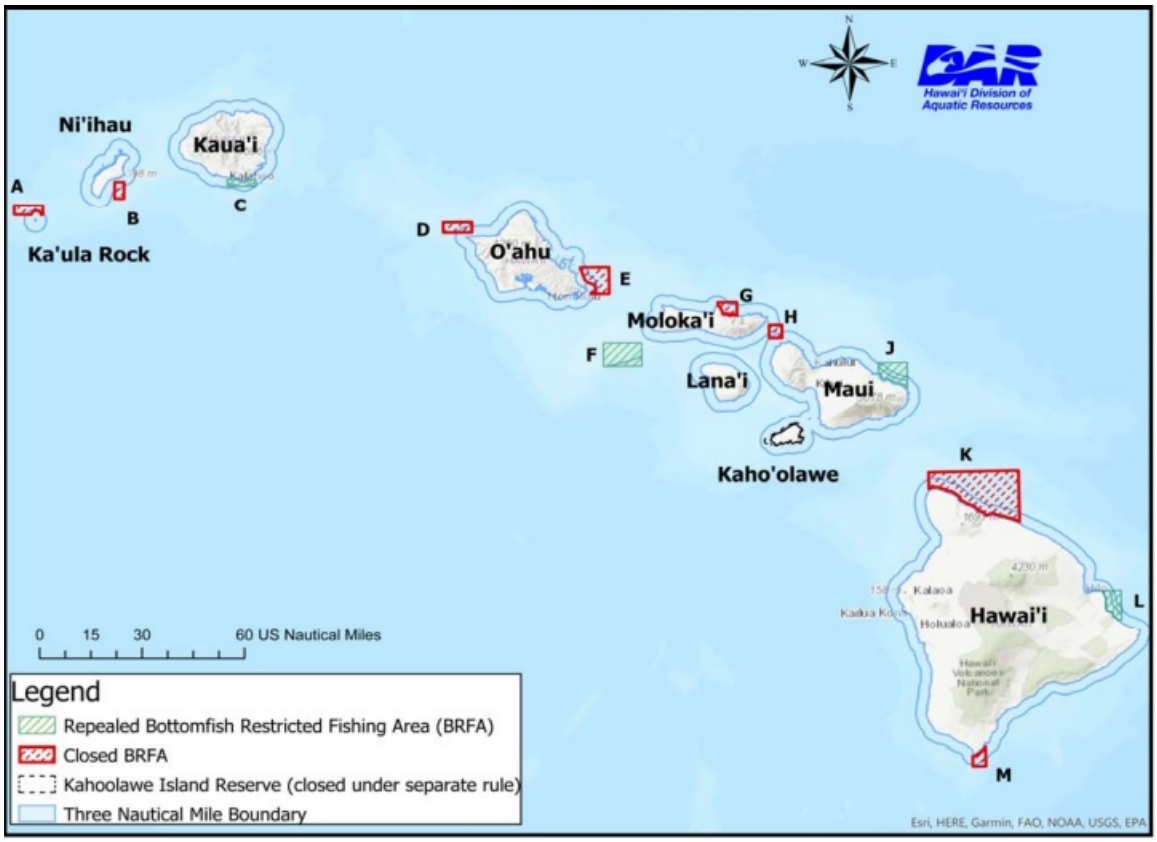

Figure 1.2 Map of the State of Hawaii's current bottomfish restricted fishing areas (BRFAs; red outlines) and recently repealed BRFAs (green outlines).

Map provided by State of Hawaii Division of Aquatic Resources[1]

The NOAA Pacific Islands Fisheries Science Center (PIFSC) is responsible for conducting stock assessments of Hawaiian bottomfish every three years to allow managers to determine the sustainability of the stock and set commercial catch limits. However, bottomfish assessments remain subject to scrutiny, partially due to (1) a historical absence of quantitative life history metrics, particularly for juveniles, and (2) the continued reliance on fishery-dependent catch and effort data as a proxy for fish abundance (Brodziak 2007, Brodziak et al. 2011).

From 2001 to 2005, a series of workshops were convened by the PIFSC to evaluate methodologies to improve bottomfish stock assessments. One major recommendation called for the utilization of "advanced technologies" for fishery-independent surveys to generate quantitative bottomfish abundance estimates and implement new length-based stock assessments (Ralston et al. 2004). As one technological alternative to extractive methods, stereo-video surveys are particularly well-suited and appropriately positioned to study fisheries impacted by overfishing, being an ideal visual sampling tool within marine protected areas (e.g., BRFAs; Drazen et al. 2014). Underwater camera systems had been used in Hawaii to study deep-water snapper juvenile nursery grounds in the late 1990s and early 2000s (Ellis and DeMartini 1995,

[1] https://dlnr.hawaii.gov/dar/files/2019/08/bfnewsvol21.pdf

Parrish et al. 1997). Beginning in 2005, stereo-camera R&D work in Hawaii used a low-light, analog system called the Bottom Camera Bait Station or BotCam (Merritt et al. 2011). This work progressed to stereo-camera pilot studies from 2011 to 2015 as a part of the implementation of a fishery-independent bottomfish survey program in the MHI (Richards et al. 2016). Based on knowledge gained from these initial efforts, the PIFSC developed the Modular Optical Underwater Survey System (MOUSS; Amin et al. 2017). Early MOUSS surveys in 2015 facilitated standardization of deployment and recovery protocols and optimized frame rates, and in 2016 the MOUSS became operational (i.e., resulting survey data was used for stock assessment purposes; Langseth et al. 2018).

At present, the PIFSC uses the MOUSS in the Bottomfish Fishery-independent Survey in Hawaii (BFISH; Richards et al. 2016) to generate species-specific, size-structured Deep 7 abundance estimates for use in stock assessments (Ault et al. 2018, Langseth et al. 2018). The BFISH data was in the 2018 Deep 7 stock assessment to (1) anchor model estimates, (2) reduce uncertainty in the assessment, and (3) improve the accuracy of values that managers use to set catch limits (Langseth et al. 2018). The MOUSS remains a crucial tool for Deep 7 stock assessments, with longer time series of survey data expected to decrease uncertainties in survey area and abundance estimates for improved population modeling and biomass-dynamic stock assessments (Ault et al. 2018, Langseth et al. 2018).

1.3 BotCam to MOUSS

Prior to development of the MOUSS, the BotCam (Figure 1.3 A) supported numerous studies (Merritt et al. 2011, Moore et al. 2013, Misa et al. 2013, Sackett et al. 2014, Misa et al. 2016, Richards et al. 2016, Oyafuso et al. 2017, Sackett et al. 2017); however, the system was heavy (~49 kg fully configured for deployment) with deployments requiring the use of a small crane, A-frame, or comparable equipment. In addition, the system's components grew increasingly obsolete, deployment configurations remained limited, and output analog, interlaced video files required manual synchronization of the left and right stereo-videos, making annotation more difficult and time-consuming. The lower resolution video also made some fish measurements challenging, especially for distant fish or low light conditions. As a result, PIFSC began development of the MOUSS in 2012 (Figure 1.3 B), to replace the BotCam in order to continue and expand stereo-camera surveys of Deep 7 bottomfish species (Amin et al. 2017).

The MOUSS was developed with the intention of improving image quality towards increased fish identification and measurement accuracy. Additional goals included (1) reduction to overall weight and gear footprint, which would allow for camera deployments from small boats, and (2) designing the MOUSS for multi-platform usage through modular system components (Amin et al. 2017).

For improved image quality, the MOUSS utilizes two Allied Vision Prosilica cameras that capture digital images at a resolution of 1936 × 1456 (horizontal vs. vertical pixels), as opposed to the BotCam's Remote Ocean Systems (ROS) Navigator™ low light cameras that record videographic images at 720 × 480 (Table 1.1). The diagonal fields of view of the two systems are comparable (MOUSS 82° and BotCam 80°), providing similar spatial coverage. While BotCam weighs approximately 49 kg with a 1.50 × 0.75 × 1.00 m frame, the smaller MOUSS weighs 29.43 kg with a 0.25 × 0.50 × 0.75 m footprint (Table 1.1). Most of the reduced mass results from the smaller and lighter MOUSS frame. The BotCam's analog video cameras capture 30

frames per second (fps) while the MOUSS's digital cameras can capture up to 40 fps. However, while the benefits of higher frame rates include smoother video and greater chances for capturing fish in orthogonal orientations ideal for accurate size measurements, higher frame rates require greater data processing and storage space. In 2016, PIFSC video analysts compared MOUSS videos with variable frame rates from 4 to 24 fps, and determined 12 fps allowed for sufficient Deep 7 bottomfish length measurements without significantly reducing measurement accuracy (Amin et al. 2017).

Both systems record imagery using ambient light to a maximum depth of 300 m for accurate species identification and sizing. Whereas quality MOUSS imagery has been obtained at 300 m on a clear day around noon, these results are not typical, thus MOUSS operations are generally limited to depths ≤ 250 m. While the MOUSS is rated to 500 m versus the BotCam's maximum operating depth of 1,000 m, this 300 m lighting constraint was factored into the design and depth rating of the MOUSS's components during the system's fabrication process.

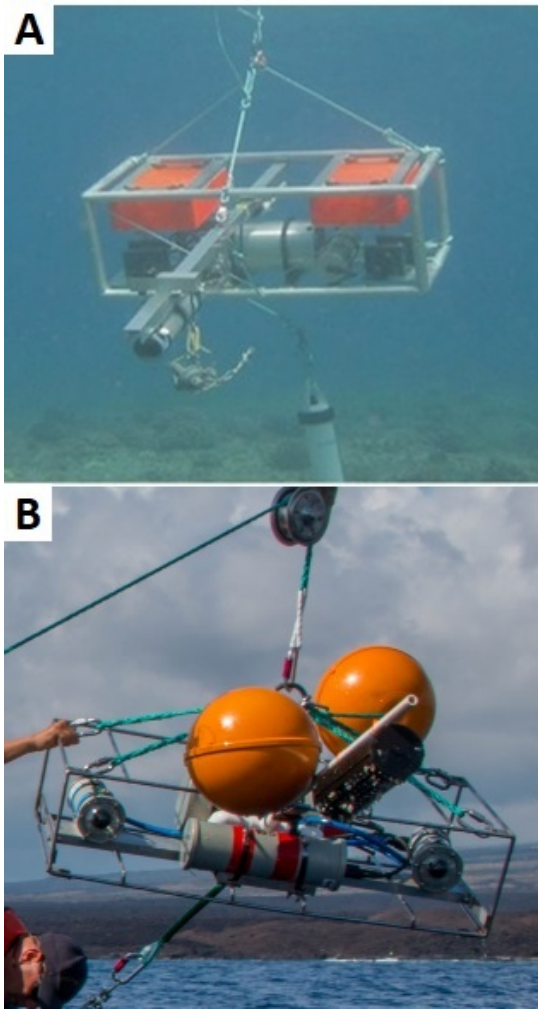

Figure 1.3 Photographs of (A) The Bottom Camera Bait Station (BotCam) at depth, and (B) The Modular Optical Underwater Survey System (MOUSS) during recovery.

Table 1.1 Comparison of BotCam and MOUSS system components and settings.

	BotCam	MOUSS
Stereo-Camera		
Camera Model	ROS Navigator™	ST-CAM-1920HD (Allied Vision Prosilica GT 1920)
Resolution	570 TV Lines-EIA RS-170, 560 TV Lines-CCIR, 720 × 480 at 30p	1936 × 1456 (2.82 Mpx)
Field of view (in water)	80º diagonal (15º horizontal)	82º diagonal (15º horizontal)
Color/Monochrome	Monochrome	Color or Monochrome*
Interface	Composite, 1.0V peak to peak into 75 ohm	Ethernet IEEE 802.3 1000baseT
Image Sensor	Interline Transfer CCD	Sony ICX674 Progressive CCD
Sensor Type (Size)	1.27 cm	11 mm
Cell Size	N/A	4.54 µm
Iris	Automatic, f/0.8–f/360	Fixed
Focus	Auto	Fixed
Exposure Control	Auto	10 µs to 60 µs; 1µs increments
Frame Rate	30 fps	0–40 fps**
Bit Depth	0.5 Mbps to 16.0 Mbps	8/14 bits ***
Binning	N/A	1–8 pixels / rows****
Gain	> 50 db	0–30 db
Power Requirement	12–30 VDC, 250 mA (max)	7–25 VDC (5 W)
Lens	3.8 mm, f/0.8	Schneider 21017528, 4.8 mm, f/1.8
Housing Dimensions	8.9–24.1 cm long	8.9–20.3 cm long
Weight Including Housing	2.58 kg / camera	2.36 kg / camera
Data Recorder		
Model	DataToys XM-DVR	ST-DVR-2HD Custom build
Operation System	Linux	Linux
Data Storage	2–32 GB SD cards, 1–64 GB CF card	2–512 GB Solid State Drives
Output	MPEG, Power Stream	DNG, JPEG, PGM, PNG TIFF, SGI*****
Power Requirement	5 VDC	9–36 VDC (16)
Housing Dimensions	36.8 × 21.6 cm	33.0 × 15.9 cm
Weight Including Housing	17.24 kg (including batteries)	8.16 kg
Power Supply		
Type	NiMH	NiMH
Duration	6–8 hrs	6 + hrs
Housing Dimensions	36.8 × 21.6 cm (same housing as DVR)	36.0 × 12.3 cm
Weight Including Housing	Included in DVR weight	7.48 kg
Complete System		
Depth Rating	1000 m	500 m
Total Weight	48.99 kg	29.43 kg
Overall Dimensions (excluding rigging)	55.8 × 45.7 × 121.9 cm	47.0 × 21.6 × 102.5 cm

Table from Amin et al. 2017. Current settings: * monochrome; **12 fps; *** 8 bits; **** 2 pixels; ***** SGI-Silicon Graphics Image.

A recent PIFSC inter-comparison study between the MOUSS and BotCam found no significant differences in bottomfish detection capabilities, relative abundance estimates, and length-based measurements between systems (Misa et al. 2020), which allowed for the continuity of stereo-videographic data streams of target bottomfish for monitoring and assessment purposes. Of the two camera systems, the MOUSS produced better quality imagery leading to more precise fish identifications (e.g., BotCam –*Naso sp.*; MOUSS –*Naso hexacanthus*) and better measurement accuracy, whereas the BotCam showed slightly higher light sensitivity at deeper sampling depths allowing detection of species (i.e. *Antigonia sp.*; *Etelis carbunculus*) missed by the MOUSS in light-limited conditions (Misa et al. 2020). Overall, the MOUSS proved to be a viable replacement to the BotCam, being capable of collecting Hawaiian fisheries survey data using only ambient light, and providing key advantages over its older counterpart.

1.4 MOUSS Configuration and Limitations

The MOUSS has been deployed as a stationary camera lander in several U.S. locations, including the Hawaiian Islands, Caribbean, Gulf of Mexico, and California. However, alternate configurations have been used depending on research focus, geography, and prevailing conditions. In Hawaii, initial efforts during the developmental phase incorporated untethered units, where an acoustic release would jettison the anchor weight, allowing the MOUSS to float to the surface for recovery. More recently, the MOUSS has been surface-tethered during large-scale (i.e. high-tempo) fishery surveys, with deployments and retrievals recovering all components including the anchors. In the Gulf of Mexico, multiple MOUSS units were outfitted with a lower frame module to rest directly on the seafloor. In this configuration, units were connected with a ground line, and deployed as a “trap string” without incorporating individual surface tackle. For California operations, the MOUSS was fitted with artificial lighting modules for use in low-light, high-turbidity waters, and Caribbean surveys coupled the MOUSS with autonomous underwater vehicle (AUV) and remotely operated vehicle (ROV) platforms.

In 2016, the MOUSS became operational for the annual Deep 7 Bottomfish Fishery-Independent Survey in Hawaii (Ault et al. 2018, Langseth et al. 2018). In addition to the BFISH survey, the MOUSS also provided additional benefits, including 1) size frequency and distributional data for life history studies of juvenile bottomfish, and 2) studies of non-target species, e.g., uku (*Aprion virescens*), oceanic whitetip sharks (*Carcharhinus longimanus*), and several other shark species.

As the MOUSS remains reliant on ambient light, sampling depths below 250 m and nighttime sampling are currently untenable. The use of active acoustic imaging systems may provide potential alternatives to optical sampling in deeper waters without the need for external lighting sources. However, concerns over effective survey range, incorrect identification of target species in mixed-species assemblages, and limited detection capabilities near the seafloor may constrain the use of acoustic technologies (Richards et al. 2016). As several target bottomfish species, particularly onaga (*Etelis coruscans*) and ehu (*Etelis carbunculus*), reside in depths beyond current MOUSS capabilities (300 to 400 m; Kelley and Moriwake 2012) and commercial bottomfishing operations often occur at night, the use of alternate technologies and survey approaches (e.g., evaluating artificial lighting on the effects on bottomfish behavior) should be further examined.

2. MOUSS Components and Electronic Accessories

The modular design of the MOUSS allows for the use of various imaging sensors, power systems, and deployment platforms. This section describes the MOUSS unit and its core modular components including cameras, digital video recorder (DVR), battery, and frame. This section also describes electronic accessories used during MOUSS operational surveys including environmental sensors and the PIFSC development of a status display system, the MOUSS Pi.

2.1 MOUSS Unit

The MOUSS unit consists of two low-light camera modules (Figure 2.1 A; section 2.2) mounted on an aluminum base bar (Figure 2.1 B), a DVR module (Figure 2.1 C; section 2.3), a battery module (Figure 2.1 D; section 2.4), and a stainless steel frame (Figure 2.1 E; section 2.5). Each underwater housing module is mounted on an aluminum "C" channel bracket with stainless steel hose clamps for secure installation and easy removal. During deployment, each MOUSS frame is suspended from a harness (Figure 2.1 F) attached to the top four corner braces and running down through the center of the MOUSS unit to an anchor weight below. The harness is designed to float the MOUSS unit approximately four meters above the seafloor, with a down-current orientation, recording images at a downward angle of approximately 15° with an 82° diagonal field of view (FOV). This configuration was chosen to match the behavior of bottomfish species known to school in the water column several meters above the benthos near hard-bottom slopes (Ralston and Polovina 1982, Haight et al. 1993). MOUSS units can also be deployed to rest directly on the seafloor, or be positioned at varying heights in the water column depending on target species and survey goals.

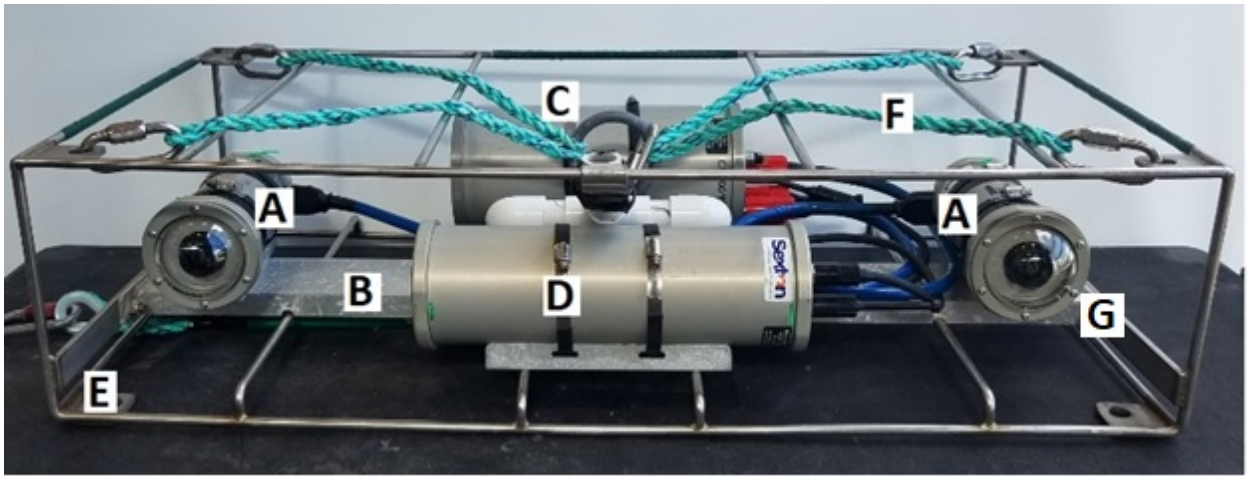

Figure 2.1 The MOUSS unit showing (A) two cameras mounted on a (B) base bar, (C) DVR, (D) battery, (E) frame, (F) harness, and (G) Temperature Depth Recorders (TDRs; not visible -behind camera).

2.2 MOUSS Camera Module

Each MOUSS camera module contains a ST-CAM-1920HD camera (Allied Vision Prosilica GT 1920, Stadtroda, Germany) fitted with 4.8 mm f/1.8 lens (Schneider 21017528, Rueil-Malmaison, France; Figure 2.2 A) and either a monochrome or colored progressive Charge

Coupled Device (CCD) capable of 2.82 Megapixel resolutions (1936 × 1456 pixels; Table 1.1). At the PIFSC, only monochrome cameras are used as they provide sufficient information to identify bottomfish species and do not require color calibration. Frame rates vary from zero to 40 frames per second, depending on the bandwidth of the recording module (DVR). The DVR has been tested at rates of up to 24 fps; however, 12 fps is the standard frame rate for PIFSC operations and analytics.

Each camera module is housed within a 500 m depth-rated underwater housing (Figure 2.2 B). Camera housings are fitted with a 7.62 cm optically correct polycarbonate dome port, providing an 82° diagonal FOV, a single female SubConn® 13-pin Power over Ethernet (PoE) bulkhead connector to the DVR as well as a pressure relief valve. Each housing has an 8.9 cm outer diameter and a 20.3 cm length, weighs 2.36 kg in air, and has a power requirement of 5 watts (W) at 7–25 volts of direct current (VDC).

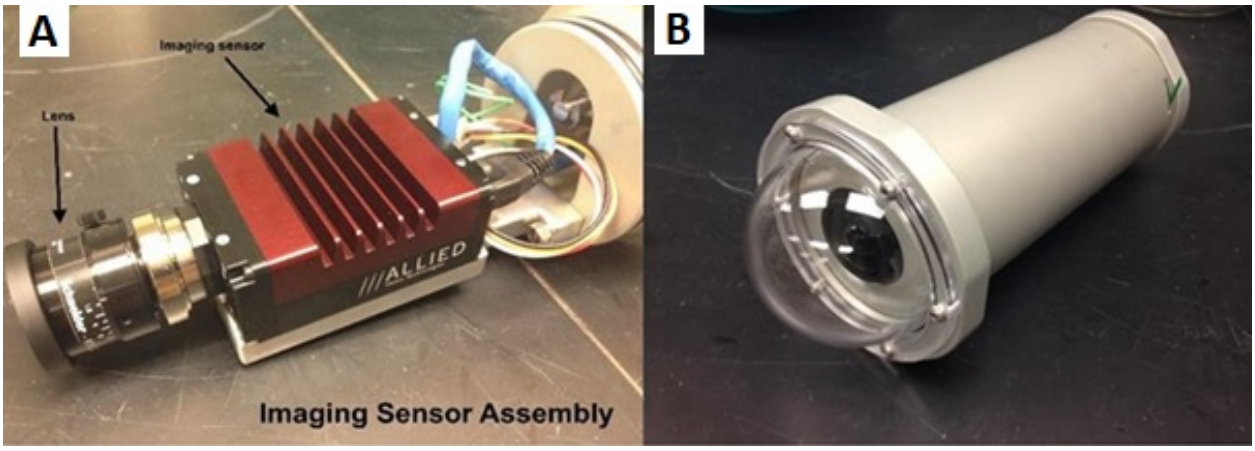

Figure 2.2 (A) The ST-CAM-1920HD camera, and (B) underwater housing.

2.3 MOUSS Digital Video Recording (DVR) Module

The ST-DVR-2HD digital video recorder (DVR; Figure 2.3 A; Table 1.1) consists of an Ethernet switch, power distribution board, two Kontron Pico-ITX-SP 1.6 GHz Intel Atom central processing units (CPU -one dedicated to each camera), and two 512-GB solid state hard drives (SSD -one dedicated to each camera), all enclosed within a 500 m depth-rated underwater housing (Figure 2.3 B). One camera serves as the master (i.e., trigger) and the other serves as the slave to maintain video synchrony. The DVR housing has a 15.9 cm outer diameter, 33.0 cm length, weighs 8.16 kg in air, with a power requirement of 16 W at 9–36 VDC. The DVR housing is fitted with three female SubConn® 13-pin PoE bulkhead connectors, a single male SubConn® 4-pin connector, and a pressure relief valve. The two outer 13-pin connectors are for each of the two cameras, while the center 13-pin connector is used for data downloads. The 4-pin connector is for the battery or connection with a Type-A NEMA 1-15 plug to a standard US alternating current (AC) electrical power outlet. As SSD technology and storage capacity improves, existing MOUSS SSDs can easily be replaced with larger and faster modules. With the current Silicon Graphics Image (SGI) 8 bits format, data can be collected for several days (3-4 days data collection or 24–32 20-minute deployments) without requiring a mandatory download. Data may be downloaded using an Ethernet cable; however, this can take several hours depending on the Ethernet speed and the amount of data retained on the DVR. The current

recommendation calls for extracting the hard drive directly for faster data transfer. As such, it takes approximately two minutes to extract and replace the hard drive. The DVR housing must be opened in a clean, dry, and protected space, which can be challenging on smaller research vessels.

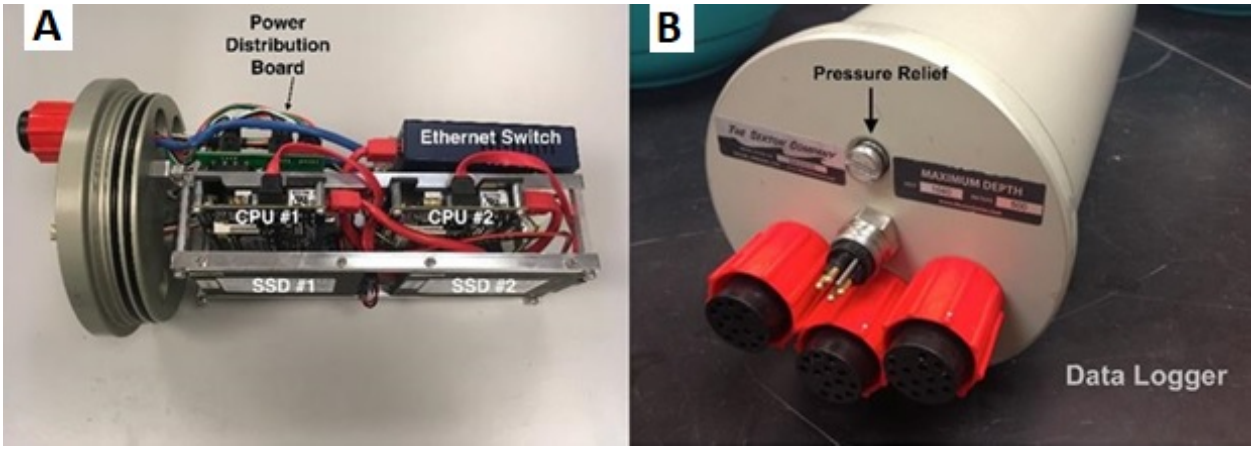

Figure 2.3 (A) The ST-DVR-2HD Digital video recorder (DVR) showing central processing units (CPUs) and solid state hard drives (SSDs), and (B) underwater housing.

2.4 MOUSS Battery Module

The MOUSS is powered by a 14.4 V, 16 ampere hour (Ah) external 16 cell nickel metal hydride (NiMH) battery pack (Figure 2.4 A). NiMH (versus lithium ion) was chosen so that MOUSS units could be easily shipped. However, lithium ion batteries can be used for MOUSS units, which are rarely (or never) shipped.

The battery is enclosed in a 12.3 cm outer diameter, 36.0 cm length, 500 m depth-rated underwater housing (Figure 2.4 B) which weighs 7.48 kg in air, with a pressure relief valve and one male and one female SubConn® bulkhead connector. The female connector connects to the DVR and is used for charging, while the male connector can “daisy-chain” multiple battery packs for longer deployments. A single battery pack can power the MOUSS for approximately six hours of recording or approximately 18–22 deployments. As battery technology improves, higher capacity and lighter weight modules may be used to replace existing components.

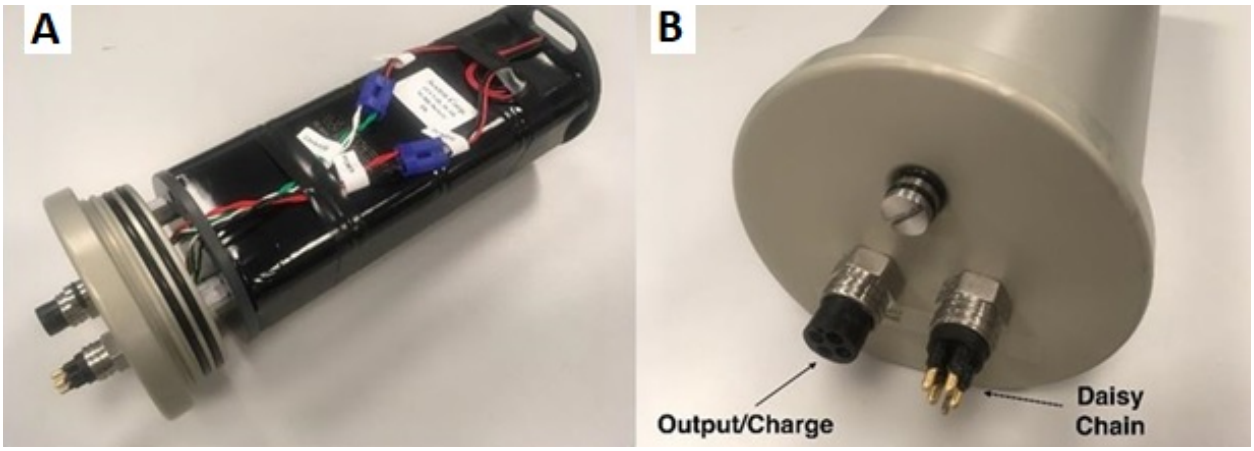

Figure 2.4 (A) The MOUSS 14.4V, 16 Ah, 16 cell, nickel-metal hydride (NiMH) battery pack, and (B) underwater housing.

2.5 MOUSS Frame Module

All MOUSS components are mounted within a stainless-steel frame (Figure 2.1 E) for protection against physical damage during deployments and retrievals. The two camera modules are mounted on a rigid base bar (Figure 2.1 B) fabricated from a 100.66 × 2.54 × 10.16 cm (l × w × h) aluminum "C" channel. Each camera is mounted using a mounting bracket fabricated from a 2.54 × 5.08 × 15.24 cm aluminum "C" channel. The base separation between the two cameras is 75 cm (same as the BotCam), with each camera converged at an inward angle of 5°. The base bar is the main structural support component for the MOUSS, and is typically mounted within the 101.60 × 42.26 × 24.13 cm stainless steel protective cage, which is sized to support additional sensor modules within it. Alternately, the base bar may be attached to a variety of different deployment platforms (e.g., larger/sturdier frames, AUVs, ROVs) depending on research focus. The MOUSS frame is capable of supporting supplementary structural components, including tri- or quad-pod legs for assessments of demersal species, which can easily be bolted onto pre-drilled mounting holes in the top and bottom corner braces. An optional bait arm is mounted on a bracket on the front of the MOUSS frame for baited deployments.

2.6 Temperature, Depth, and Conductivity Sensors

The MOUSS does not host integrated depth or temperature sensors. As such, PIFSC MOUSS surveys utilize either Temperature Depth Recorder (TDR) or Conductivity Temperature Depth (CTD) sensors to measure camera deployment depths and water temperatures. Currently, SeaBird SBE-39 CTDs (48 × 369 mm; Figure 2.5 A) are used if a higher degree of accuracy and precision is required (e.g., during camera testing and R&D work), and smaller, inexpensive Lotek LAT 1400 TDRs (35 × 11 mm; Lotek Wireless, Ontario, Canada; Figure 2.5 B) are used for MOUSS bottomfish surveys. During bottomfish surveys, two replicate TDRs are mounted on each MOUSS unit. The TDRs are programmed to record depth and temperature at 30-second intervals, and the data is downloaded at the end of each day's operations. For each MOUSS deployment, the depth and temperature are calculated by finding the mode of the 30 measurements recorded from the time the MOUSS touches down on the seafloor to the end of the 15-minute video analysis period. The mode of the two replicate TDRs are averaged to get the final deployment depth and temperature readings.

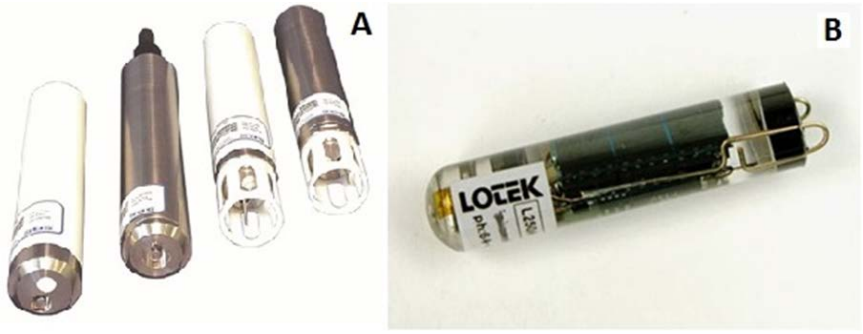

Figure 2.5 (A) Conductivity Temperature Depth (CTD), and (B) Temperature Depth Recorder (TDR) sensors.

2.7 The MOUSS Pi

The MOUSS does not have any visual displays to indicate whether both cameras are "ON" and functioning properly before deployment. Prior to 2018, the only way to assess whether MOUSS cameras were properly recording was to connect the MOUSS to a computer via Ethernet cable to check camera log files directly. With the majority of PIFSC MOUSS operations conducted from small boats vs. large research vessels, this was impractical, requiring a field computer, dry deck space protected from environmental conditions, a technician proficient in Linux, and considerable time. This resulted in up to 7.1% of deployments with missing stereo-video data due to an unobservable camera issue (e.g., one or both cameras not turning "ON" before deployment). This data loss was equivalent to a full day of small boat operations on a 15-day research survey.

As a result, a MOUSS status display system called the "MOUSS Pi" was developed in 2018 to confirm the operational status of the cameras prior to each deployment. The MOUSS Pi was built using off-the-shelf electronics and hardware, and the housing was printed using onsite 3-D printers. All MOUSS Pi R&D work, fabrication, and software development was conducted in the PIFSC Marine Instrumentation Labs (MILs). The MOUSS Pi's display system required adequate processing power somewhere between that of a microcontroller and a laptop computer. A Raspberry Pi was chosen as the cheapest and most effective device available that would meet processing requirements. Additionally, the Raspberry Pi has a large user community that produces many helpful low-cost add-on components to increase device utility. The MOUSS Pi system was designed to be used primarily on small boats, so a splash-proof housing and low rate of power consumption were crucial since recharging or replacing a battery is not feasible on a small boat. The MOUSS Pi was built using readily-available off-the-shelf components (Table 2.1) at a total cost of approximately $125 USD per unit. The device has a simple wiring design (Figure 2.6) with an Ethernet cable for connection to the MOUSS DVR, a universal serial bus (USB) charging cable, and a simple screen to display the camera status for both master and slave cameras (Figure 2.7).

Table 2.1 The MOUSS Pi components and their costs.

Component description	Cost
PaPiRus 2.7" eInk Display HAT for Raspberry Pi from Pi Supply	$49.95
Raspberry Pi 3—Model B—ARMv8 with 1G RAM	$35.00
PowerBoost 1000 Charger	$19.95
Lithium Ion Battery Pack—3.7V 4400mAh	$19.95
Total	**$124.85**

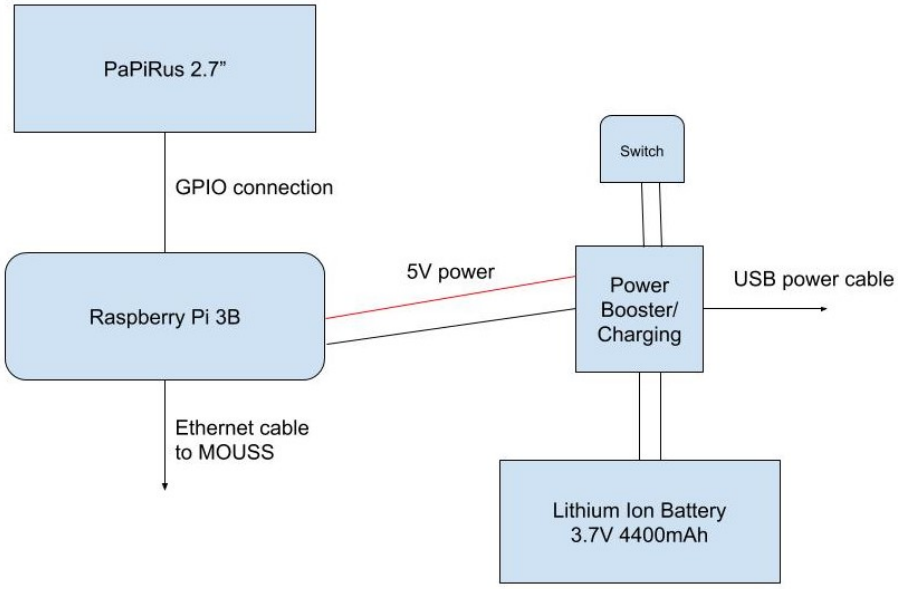

Figure 2.6 Wiring diagram for the MOUSS Pi.

Figure 2.7 The MOUSS Pi-1.

The first version, referred to as "MOUSS Pi-1" (version 1.0), displayed the camera status as "ON" or "OFF," the date and time in UTC, and video file names for both master and slave cameras. When both cameras were properly recording, the display screen read "MOUSS READY". The MOUSS Pi-1 was bench tested extensively in the lab, during MOUSS camera calibrations, and in the field from small boats prior to being used for research missions. The MOUSS Pi-1 became operational in September 2018, when three MOUSS Pi-1 units were used for Deep 7 bottomfish surveys. As a result, the rate of data-loss due to one or both cameras failing to record declined from 7.1% to 0% (Table 2.2).

Table 2.2 Comparison of MOUSS Pi-1 use versus percentage of lost data.

Hawaiian Bottomfish Surveys	**Fall 2017 Survey No MOUSS Pi**	**Fall 2018 Survey With MOUSS Pi-1**
Total number of deployments	198	288
One or both cameras did not record	14	0
% deployments with lost data	**7.1**	**0**

Following the success of the MOUSS Pi-1, the "MOUSS Pi-2" represented an improved user-friendly, robust, and more weatherproof version (version 2.0; Figure 2.8). The MOUSS Pi-1 utilized a 3-D printed housing to host the internal electronics; however, this did not offer adequate protection against the elements (i.e. moisture, salt-spray, etc.). The MOUSS Pi-2, incorporated all electronics inside a 1200 Pelican case (270 × 246 × 124 mm), with an aluminum cover plate for protection. Additionally, new parts were 3-D printed to hold all electronics to the aluminum plate with a weatherproof ring. Control buttons were updated to red and yellow "arcade" style buttons for ease of use when checking MOUSS status. When both the master and slave cameras are recording properly, the MOUSS Pi-2 display screen reads "SYNC".

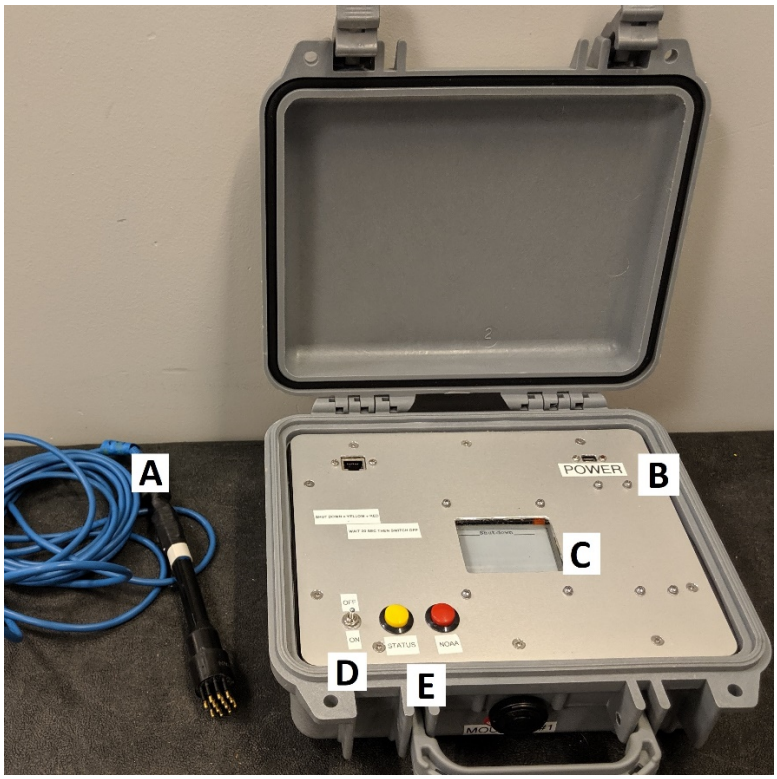

Figure 2.8 The MOUSS Pi-2 showing (A) Ethernet cable for connection to MOUSS, (B) charging port, (C) display screen, (D) power switch, and (E) arcade style control buttons.

3. MOUSS Calibration

For accurate and precise quantitative fish measurements, underwater photographic stereo systems must be geometrically calibrated and imagery from both cameras must be precisely synchronized in time. The calibration accounts for known factors that cause imagery distortions, including timing and scale errors, along with camera orientation parameters, e.g., stereo-camera base separation, focal length, lens distortion, and refraction effects at air-glass and glass-water interfaces of underwater camera housings (Harvey and Shortis 1998). Most calibration techniques rely on a calibration object with predefined dimensions. Two of the most common methods for stereo-camera calibration involve the use of a two-dimensional (2-D) checkerboard (Bouguet 2004) or a three-dimensional (3-D) "calibration cube", with defined measurement "points" (Clarke and Fryer 1998). A recent review of calibration techniques concluded that measurements made with 3-D cubes displayed higher accuracy and precision (Boutros et al. 2015). Additionally, the use of calibration cubes allows for accurate measurements over a wide range of distances, whereas the 2-D checkerboard method is inherently planar, subjecting it to unpredictable variations in calibration parameters and decreased measurement accuracy (Boutros et al. 2015).

The general approach with calibration cubes involves the utilization of a purpose-built 3-D cube, which is rotated within the fields of view of the cameras from which distance measurements can be made. These measurements are used to calculate a photogrammetric network solution based on collinearity and least squares estimation to rigorously model the network geometry and random errors in the measurements (Clarke and Fryer 1998). Standardized stereo-video calibration techniques utilizing calibration cubes with specialized software packages, such as CAL (SeaGIS Pty. Ltd., Victoria, Australia), can reliably provide photogrammetric network solutions. This allows fisheries researchers to generate accurate and repeatable fish length measurements (following proper calibration techniques) without requiring an in-depth knowledge of photogrammetric theory (Boutros et al. 2015). Each MOUSS stereo-camera pair is accurately and precisely calibrated in this fashion using SeaGIS CAL software.

The calibration process is specific to a single field effort for each stereo-camera pair and base bar combination. Currently, PIFSC MOUSS cameras are calibrated using a standardized calibration cube with a 1.0 × 1.0 × 0.5 m custom-made 3-D cube (SeaGIS Pty. Ltd., Victoria, Australia), with 77 white dots or "points" of precisely-known spacing (Amin et al. 2017; Figure 3.1). As the MOUSS cameras record imagery, the MOUSS and the cube are placed in a tank of seawater deep enough to completely cover the cube. The cube is centered approximately 1.5 m in front of the paired MOUSS cameras so that the cube fills most of the field of view. Two people stand in the tank alongside the cube (Figure 3.1) and move the cube into five different orientations: forward-facing, tilted forward 15°, tilted backward 15°, angled to the left 15°, and angled to the right 15°. At each orientation, the cube is held motionless for 3 seconds to ensure clear imagery. Care is taken to avoid obscuring any of the points with the hands or body, as this may reduce calibration accuracy. Following completion of five orientations, the cube is rotated 90° and the same five orientations are repeated in sequence. This continues until five orientations for each of the four sides have been completed, producing a total of 20 cube orientations recorded for each camera pair. A striped mark on the cube's corner indicates the starting position, ensuring that all five cube rotations are made.

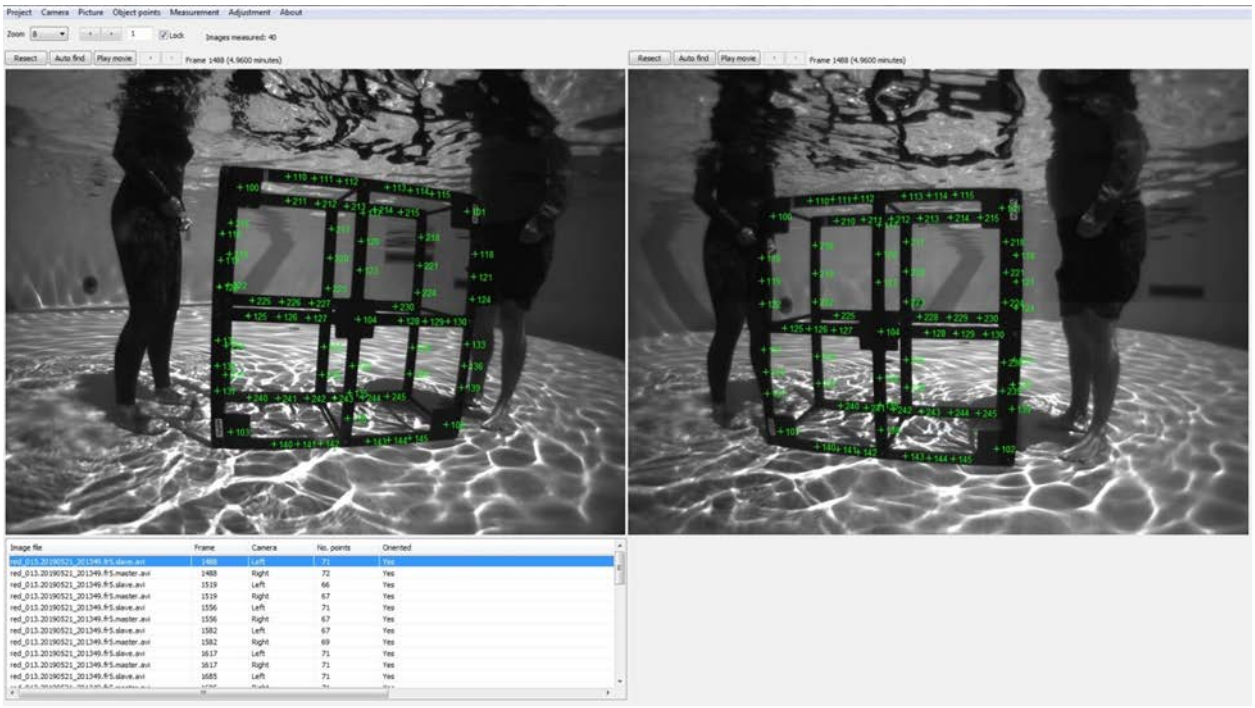

Figure 3.1 Screengrab of CAL software showing underwater 3-D "calibration cube" recorded for MOUSS calibration for both the left and right video screens. Calibration points are marked in green.

MOUSS calibrations use SeaGIS CAL software, version 3.21 (SeaGIS Pty. Ltd., Victoria, Australia; Seager 2008). The paired calibration videos are synced and paused on a frame in which the points appear clearly visible. Each of the calibration cube's four corner points are marked using a centroiding function. The CAL software automatically populates the locations of the remaining points (Figure 3.1). Depending on orientation, some points will naturally be obscured by the calibration cube itself. Point processing is repeated for each of the 20 paired calibration cube orientations to produce a total of 40 point files. The exact distance between each of the points is precisely known, and the software compares these to the measured distances from the point files, calculating a bundle adjustment and producing a left-right set of calibration files for the camera pair. The bundle adjustment also yields the calibration's precision with a relative precision of at least 1:5000 required for the calibration to be deemed acceptable. If the precision value is not within the acceptable level, the point selection process may be partially or entirely repeated to improve "bad" points until an acceptable precision is reached. In worst-case scenarios, the cube rotations may need to be repeated (e.g., if the cube is too near/too distant from the cameras).

For each calibration, measurement accuracy is calculated using SeaGIS EventMeasure™ software, version 5.25 (SeaGIS Pty. Ltd., Victoria, Australia; Seager 2008). The calibration videos and corresponding calibration files are used to measure distances between a subset of points on the calibration cube, which are then compared to the actual known point distances. If all measurements are accurate within 2 mm, the calibration is considered acceptable and the camera calibration files are later used during video annotation. Camera calibrations are performed both before and after each survey mission to ensure that jostling during transport,

deployment, and recovery has not altered the orientation of the cameras, invalidating a pre-survey calibration. If one of the stereo-cameras of a calibrated pair is intentionally replaced with a spare or adjusted in any way, the pre-survey calibration files must be used to annotate all videos recorded before the camera change occurred, while the post-survey files must be used to annotate all videos recorded after the change occurred. This ensures that accurate fish measurements are obtained at all times. The complete step-by-step protocol for MOUSS stereo-camera calibration using SeaGIS CAL (version 3.21) and EventMeasure™ software (version 5.25) can be found in Appendix A: MOUSS Calibration Protocol.

4. Sampling Strategies, Field Deployment and Recovery

The PIFSC MOUSS deployments primarily occur from small boats (5.8 m), but a subset occurs from larger research vessels. Small boat deployments are considerably more efficient due to their increased speed and maneuverability, whereas ship-based deployments involve simultaneous data collection with other paired research projects, and testing for the development of new technologies. Ship-based deployments are also slower due to several intrinsic limitations (e.g., crane and J-frame operational requirements; scientist-to-deck communication protocols). This section describes general sampling strategies and survey design, MOUSS deployment and recovery protocols from small boat platforms, and modifications required for ship-based deployments.

4.1 Sampling Strategies and Survey Design

BFISH surveys utilize a two-stage stratified random sampling design as described in Richards et al. (2016) which includes a combination of extractive research fishing and MOUSS camera surveys. These surveys occur across the main Hawaiian Islands between 75 to 400 m, although MOUSS surveys are typically limited to depths ≤ 250 m due to ambient light limitation (i.e., only research fishing occurs to 400 m). Survey sites are randomly allocated to 500 × 500 m sample units (“grid cells”; Figure 4.1), and stratified according to three depth categories: (1) shallow: 75 to < 200 m; (2) medium: ≥ 200 to < 300 m; and (3) deep: ≥ 300 to 400 m. In addition, three substrate composition-complexity categories are assigned based on projected habitat type, derived from available multi-beam backscatter data: (1) soft-bottom, all slopes; (2) hard-bottom, low-slope; and (3) hard-bottom, high-slope (Richards et al. 2016, Ault et al. 2018).

Two replicate, spatially randomized MOUSS camera deployments are conducted within each randomly allocated grid cell at least 150 m apart. Occasionally, precise deployment locations may be preassigned to target specific areas within the grid cell which best represent the assigned grid cell strata (e.g., deployments may target known hard-bottom areas within a “hard-bottom” grid that has partial soft-bottom substrate composition). Cameras are activated (recording) and deployed for a total time of 20 minutes, which includes a seafloor video data collection time of at least 15 minutes, plus an approximately 5-minute buffer to account for the MOUSS’s descent to the seafloor. A standardized 15-minute video data collection time allows for increased levels of field sampling, and reduced video-processing time, while maintaining the power to detect differences in Deep 7 bottomfish relative abundance and lengths (Misa et al. 2016). However, data collection times can vary depending on target species and research objectives (e.g., longer video data collection times may be needed for holistic community assessments or estimating diversity metrics).

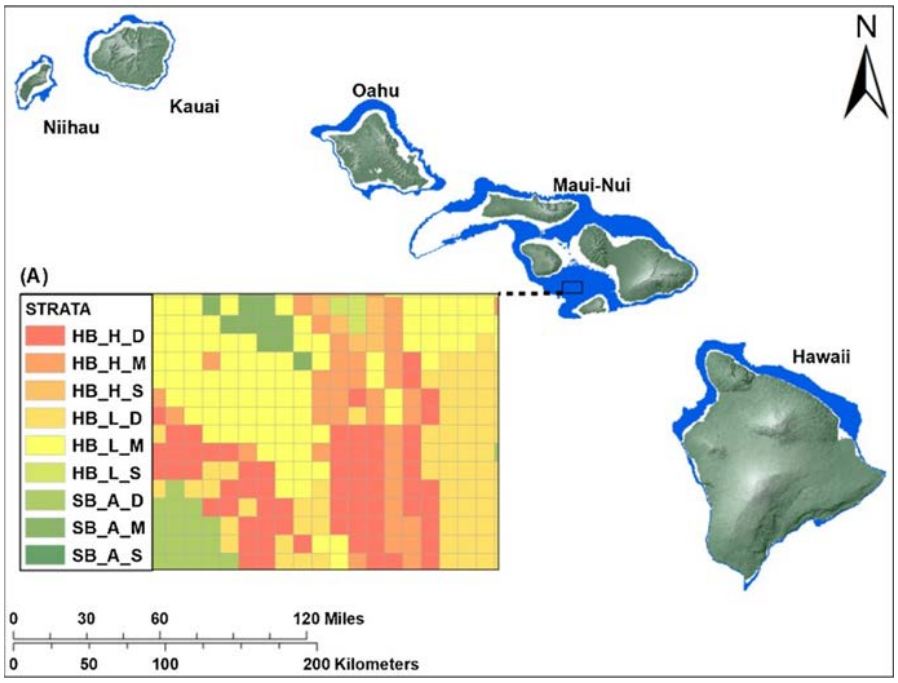

Figure 4.1 Map of BFISH survey areas (blue), with inset showing an example of stratified depth and substrate types in 500 × 500-m grid cells.

Strata are coded as bottom type_slope_depth, with bottom type_slope as hard-bottom (HB) high-slope (H) or low-slope (L), or soft-bottom (SB) all slopes (A), and depth as deep (D), medium (M), or shallow (S). Map from Ault et al. (2018).

All survey metadata are manually recorded on data sheets, then transcribed and saved as an Excel file or Google sheet. This "Survey Metadata Sheet" is named after the survey name (e.g., "SE-17-01 Survey Metadata" named after the ship cruise number; see sections 5.1 and 5.2 for thorough explanations of MOUSS file naming conventions). Google sheets are preferable to Excel files since they can be shared. In addition, Google sheets access permissions can be easily regulated depending on the user (e.g., "can edit," "can comment," and "view only" settings).

Survey metadata include: survey date and local (Hawaii) deployment time, grid cell number, MOUSS video filenames (obtained from the "MOUSS Pi"; see section 2.7 The MOUSS Pi), vessel used for MOUSS deployment (name), MOUSS ID/name, DVR name, deployment depth in meters, position (latitude and longitude in decimal degrees), GPS unit identification number, and identifying information for any other sensors attached to the MOUSS frame (e.g., TDRs, CTDs). The information contained in the Survey Metadata Sheet is referenced later during video annotation.

4.2 Field Deployment and Recovery from Small- and Medium-sized Boats

PIFSC primarily uses the previously described 5.8 m (19 ft) SAFE Boats™ (Figure 4.2 A), but similar deployment strategies can be used with medium-sized fishing boats (12–18 m; Figure 4.2 B). The majority of MOUSS deployments occur from small boat platforms (Table 4.1), since they are faster and more maneuverable than larger research vessels.

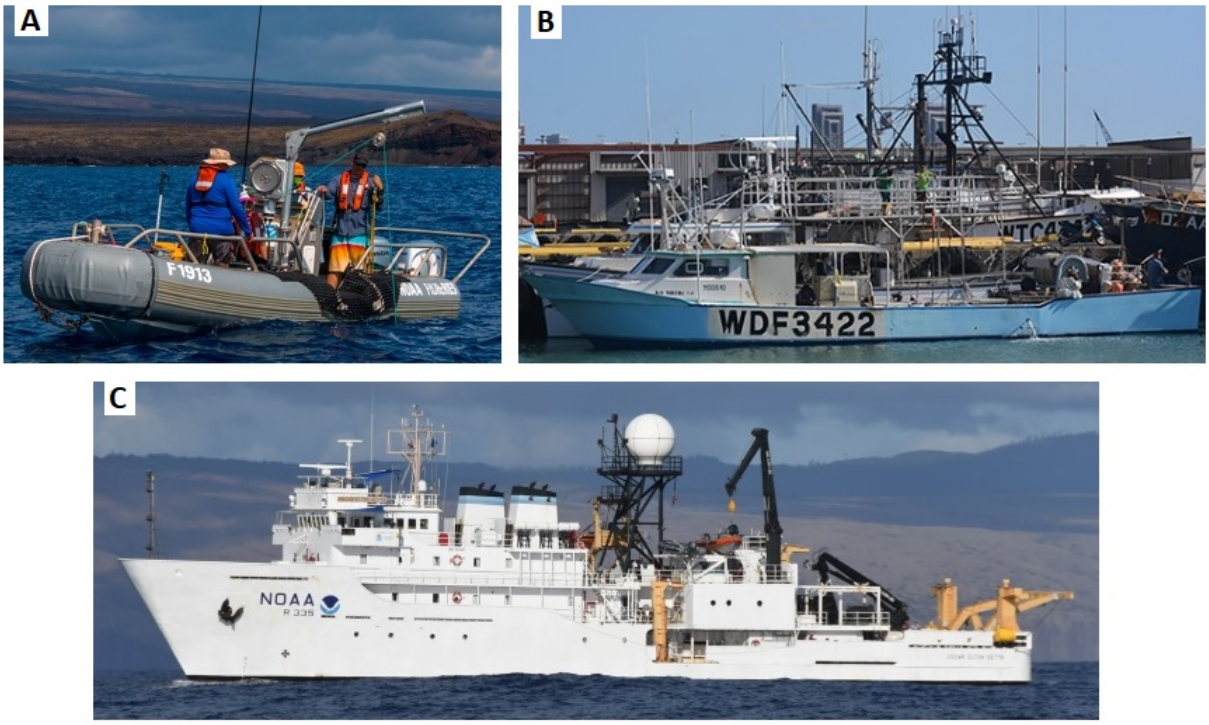

Figure 4.2 Photos showing typical MOUSS deployments platforms, including (A) *Steel Toe*, a PIFSC small boat, (B) *Ao Shibi IV*, a medium-sized fishing boat, and (C) NOAA Ship *Oscar Elton Sette*, a large research vessel.

Photos courtesy of (A) the authors, (B) Susan Yamamoto/Maritime Hawaii, and (C) NOAA Fisheries.

Table 4.1 Number of MOUSS deployments by small (5.8 m), medium (12–18 m), and large (60 m) deployment platform for 2016 through 2019 BFISH surveys.

	Deployment Platform			
BFISH Survey Dates	Small Boat	Medium Boat	Large Ship	Total
10/14/2016 – 11/3/2016	153	0	45	198
10/21/2017 – 11/17/2017	203	41	44	288
9/20/2018 – 11/27/2018	187	60	60	307
9/12/2019 – 11/26/2019	270	50	104	424

The MOUSS is typically deployed with modules as described in previous sections. Support accessories include: two sub-surface floats, a bait arm with plastic bait container and attached "light synchronization" device, a surface line with two surface buoys, an anchor weight, and a bottom line attached to the anchor (Amin et al. 2017; Figure 4.3). The buoyant force of the surface buoys and the weight of the anchor are distributed along the surface line (Figure 4.4 A), which passes through the center of the MOUSS frame, tethered 4 m above the seafloor at the harness ring. This design ensures minimal frame distortion, regardless of load. Two sub-surface floats (Figure 4.4 B) attached at the harness ring provide sufficient positive flotation to

counteract the weight of the MOUSS unit, making the MOUSS unit effectively neutrally buoyant. The optional bait arm (Figure 4.4 C) acts as a rudder to help orient the cameras field of view down-current. Bait consists of approximately 0.45 kg mixed ground squid and mackerel, similar to bait used by bottomfish fishermen and natural diets containing both fish and cephalopods (Haight et al. 1993). On the end of the bait container facing the cameras is a custom-built “light synchronization” device (Figure 4.4 C, inset) mounted inside a 500-m rated housing. The device uses a ring of light emitting diodes (LED) which blink at a frequency similar to the cameras frame rate at 60-second intervals (Harvey and Shortis 1995). During video annotation, the light sync is used to synchronize the left and right stereo-videos if they become out-of-sync as a result of dropped frames or camera failure issues (<5% of videos). If the anchor weight becomes trapped or snagged on the seafloor, a thinner section of 0.635-cm line nearest the weight (Figure 4.4 D) is designed to chafe and break, allowing the MOUSS to be recovered. During recovery, the surface buoys are retrieved using a boat hook, and the surface line is recovered with the help of an electric pinch puller and davit (Figure 4.2 A). The anchor weight is secured first; the MOUSS is then brought onboard; and finally, the anchor weight is recovered using the pinch puller. The complete step-by-step MOUSS deployment and recovery protocols can be found in Appendix B: MOUSS Deployment and Recovery Protocol.

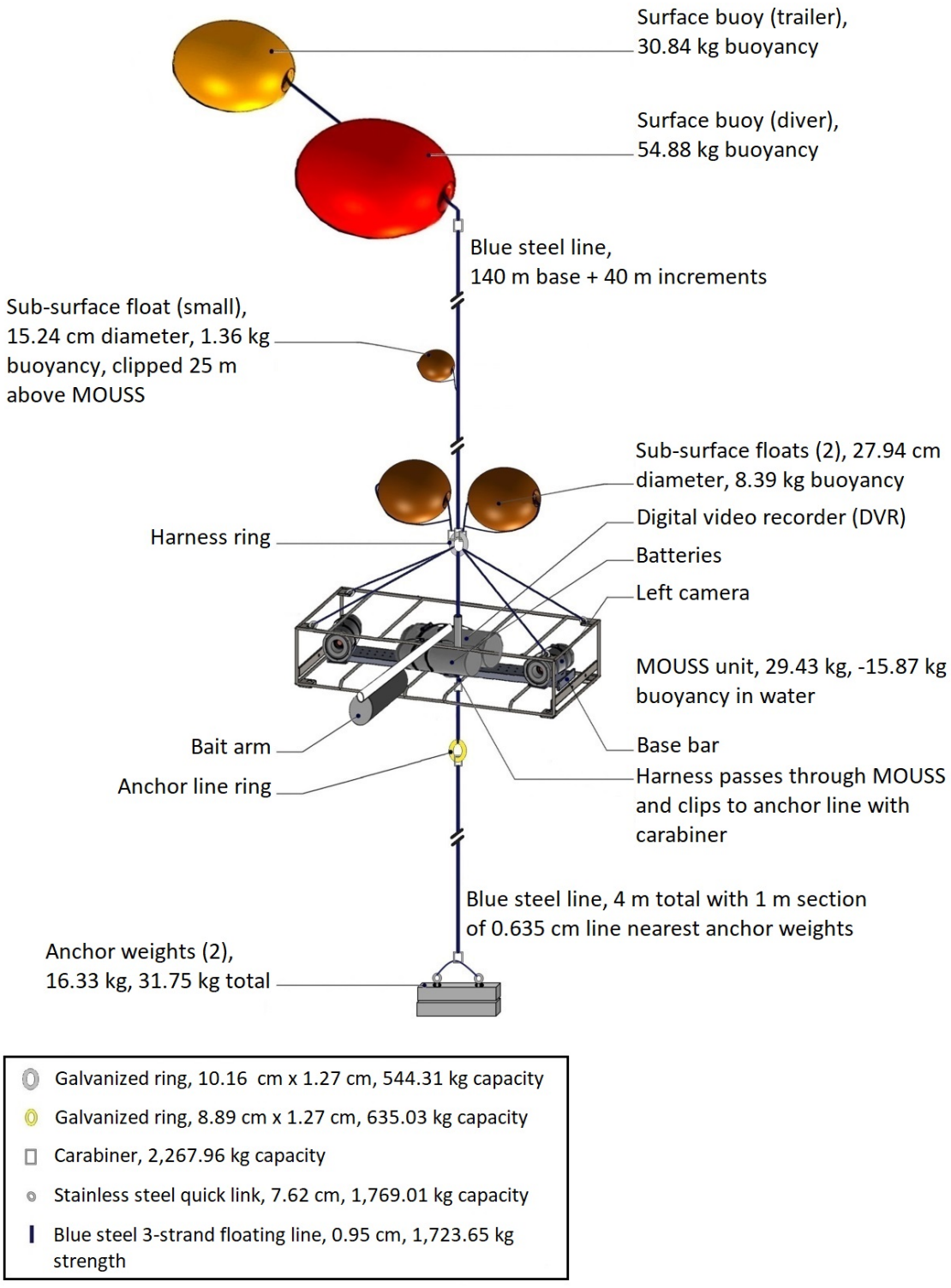

Figure 4.3 Diagram of the MOUSS showing the stereo-video components mounted on the base bar within the frame suspended by sub-surface floats above the anchor weight, and surface buoys running up to the surface.

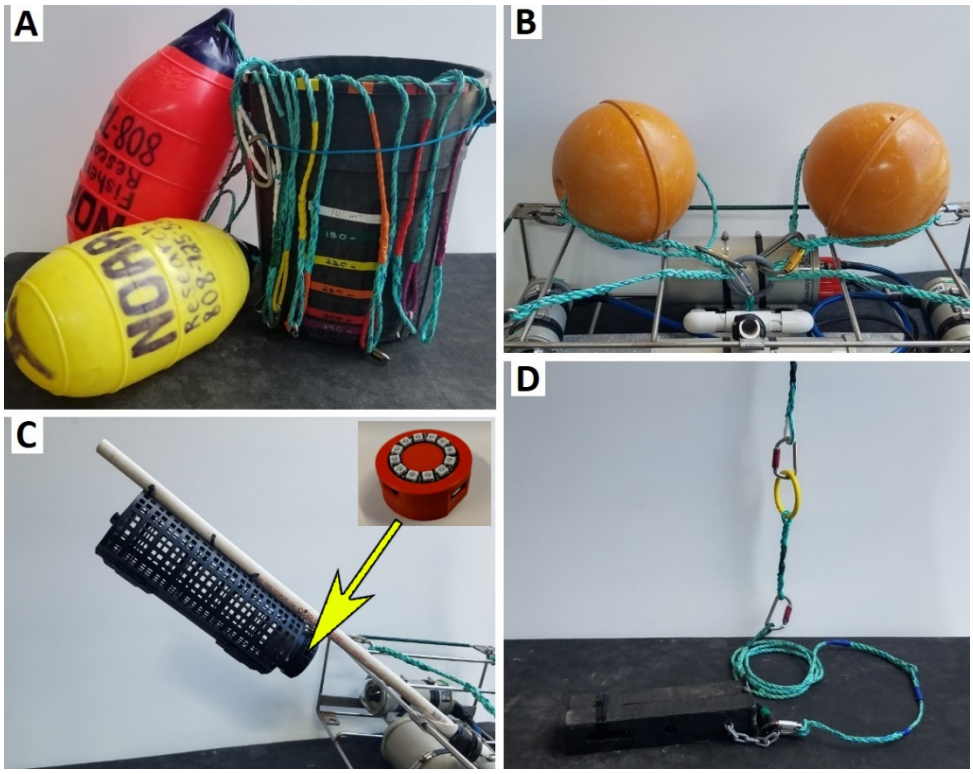

Figure 4.4 MOUSS deployment accessories including (A) surface buoys and surface line, (B) sub-surface floats, (C) bait arm and light synchronization device (inset), and (D) bottom line and anchor weight.

4.3 Modifications for Deployment and Recovery from a Large Vessel

MOUSS operations conducted from a large research vessel (60 m; Figure 4.2 C) may incorporate several modifications to strengthen the unit against the inherent physical stresses encountered (when compared with small boat operations). Large vessel-based deployments may utilize a knuckle crane (Figure 4.5 A), A-frame, or J-frame utilizing large-scale hydraulics vs. the much smaller electric pinch puller. This may require thicker line (1.27 vs. 0.95 cm) to ensure proper haul-back strength and durability. Additionally, the MOUSS cameras, DVR, and battery components may need to be attached to larger and sturdier frames (Figure 4.5 B) to ensure module protection. Additional anchor weights and sub-surface floats may help stabilize and support larger, heavier deployment packages. In order to improve MOUSS recovery success rates, jettisoning of anchor weights (e.g., concrete blocks; Figure 4.5 C) is possible via acoustic release (Figure 4.5 D) which is activated with a surface signal. Ideally (for survey efficiency), the MOUSS (including anchor weights) is fully recovered during haul back; however, an acoustic release provides the increased probability that the MOUSS can be successfully recovered under less-than ideal conditions or if the anchor weight becomes caught on the bottom.

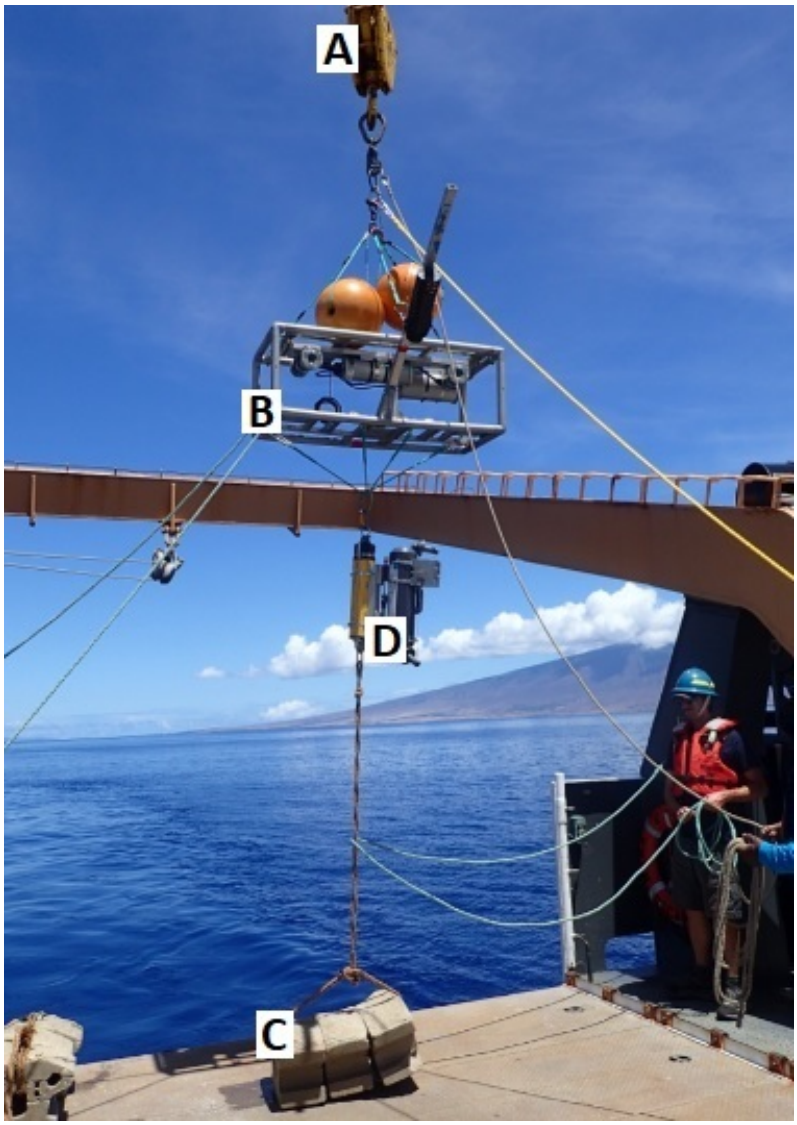

Figure 4.5 The MOUSS configured for deployment from a large ship showing use of (A) a knuckle crane, (B) sturdier frame, (C) jettisonable anchor weight, and (D) acoustic release.

5. MOUSS Data: Structure, Processing, and Video Annotation

MOUSS deployments generate a variety of data products including metadata, digital images, and environmental sensor data. This section describes the MOUSS video data file naming convention, InPort metadata structure, data download and generation of video archives, and video annotation protocols.

5.1 MOUSS Video File Name Convention

The MOUSS can store images in various image formats (see Amin et al. 2017 for more details). At present, the NOAA PIFSC uses raw Silicon Graphics Image (SGI; .sgi files) format images which are converted to audio video interleave (AVI; .avi files) videos for subsequent annotation.

The general form of a MOUSS video filename is
iyyyymmdd_hhmmss_lll_c_ff.avi, where

i = instrument identifier (M for the MOUSS, B for the BotCam)
yyyymmdd = UTC date as year (four-digit number -yyyy), month (two-digit number -mm), and day (two-digit number -dd)
hhmmss = MOUSS activation time (UTC) as hours (two-digit number -hh), minutes (two-digit number -mm), and seconds (two-digit number -ss). The activation time for the master and slave cameras will often differ by a second or two; this is normal.
lll = optional three-character location identifier (e.g., MHI for Main Hawaiian Islands)
c = camera identifier (m for master/right camera; s for slave/left camera)
ff = frame rate per second (fps)

Example MOUSS video filenames used in this document include
M20170101_180514_MHI_m_12.avi: MOUSS main Hawaiian Islands master/right video at 12 fps for a survey conducted on January 1, 2017 with an activation time of 18:05:14 UTC.
M20170101_180513_MHI_m_12.avi: MOUSS main Hawaiian Islands slave/left video at 12 fps for a survey conducted on January 1, 2017 with an activation time of 18:05:13 UTC.

5.2 MOUSS InPort Metadata Management Protocols

Following each MOUSS survey, all metadata is published in InPort (https://inport.nmfs.noaa.gov/; Catalog Item ID: 51818) including appropriate contact information and instructions for how to access video data, which fulfills federally mandated public data sharing requirements. An example of InPort metadata is shown in Table 5.1.

Table 5.1 InPort Metadata File Structure.

Cruise_ Name	Date	Day_of_the_ Year	Region	Latitude	Longitude	Depth	Temperature	Master_Video_ Filename	Slave_Video_ Filename
SE-17-01	1/1/2017	1	MHI	21.625261	-158.324369	211.81	15.2	M20170101_180514_MHI_m_12.avi	M20170101_180513_MHI_s_12.avi
SE-17-01	1/1/2017	1	MHI	21.615921	-158.346195	223.69	15.3	M20170101_192306_MHI_m_12.avi	M20170101_192305_MHI_s_12.avi
SE-17-01	1/1/2017	1	MHI	21.616459	-158.344578	217.75	15.9	M20170101_194558_MHI_m_12.avi	M20170101_194559_MHI_s_12.avi

Note: Internal PIFSC metadata records include significantly more parameters including metrics used to track camera, DVR, and battery performance over time, MOUSS deployment and recovery notes, and weather/sea conditions.

Cruise_Name: SN-FY-CN, where SN is the two-letter abbreviation for the ship's name, FY is the two-digit fiscal year (defined as 1 October to 30 September), and CN represents a two-digit cruise number with a leading zero (e.g., SE-17-01 represents NOAA Ship *Oscar Elton Sette* (SE), fiscal year 2017 (17), and cruise number 1 in FY17 (01)).

Date: UTC survey date, mm/dd/yyyy, where mm is the two-digit month without leading zeros, dd is the two-digit day of the month without leading zeros, and yyyy is the four-digit year.

Day_of_the_Year: Three-digit UTC day of the year without leading zeros.

Region: Three-character abbreviation for the region where the survey was conducted (e.g., MHI for the main Hawaiian Islands).

Latitude: MOUSS surface deployment latitude in decimal degrees (up to 6 decimal points).

Longitude: MOUSS surface deployment longitude in decimal degrees (up to 6 decimal points).

Depth: MOUSS deployment depth in meters as recorded by the Temperature Depth Recorder (see section 2.6 Temperature, Depth, and Conductivity Sensors for more information). Note that this is not the seafloor depth; the MOUSS is deployed 4 m above the seafloor (may be less in strong current).

Temperature: Temperature at MOUSS deployment depth in °C (up to 2 decimal points) as recorded by the Temperature Depth Recorder.

Master_Video_Filename: Filename of the video created from the master camera.

Slave_Video_Filename: Filename of the video created from the slave camera.

5.3 MOUSS Data Download and Video Generation

Following daily MOUSS deployments, DVR housings are opened and the two internal SSDs are extracted. The raw SGI images are downloaded to a primary storage hard drive (HD), converted to AVI video files (two per deployment–one for the master and one for the slave), with both the

original images and video files backed up to a duplicate secondary HD. A Linux Ubuntu operating system is used for all raw data downloads and video processing, with Perl scripts automating video creation. For the rapid assessment of image quality, 100 evenly spaced SGI images are converted to jpeg images for each deployment and checked for potential issues (e.g., image blur, ambient light quality, and dropped frames). In addition, all videos are rapidly scanned following file creation to ensure video integrity for subsequent annotative analysis. These quality control checks allow for appropriate adjustments (if needed) prior to the next day of MOUSS deployments.

After 3–4 days of data collection the MOUSS SSDs are typically full, and data is deleted to ensure enough space is available for subsequent deployments. For detailed MOUSS data download and video generation protocols, please see Appendix C: Linux Commands for Data Download and Video Creation, and Appendix D: MOUSS Perl Scripts.

5.4 MOUSS Video Annotation

MOUSS video annotations occur within previously established guidelines [i.e. identification of all fish species observed within the 15-minute analysis period; enumeration and measurement of Deep 7 bottomfish (Figure 5.1) target species]. Taxonomic identifications are made to the lowest level of annotative certainty, based on image quality. Factors that may individually, or collectively, result in reductions to identification specificity include low ambient light, turbid water conditions, and distance from the MOUSS. Fish at extreme distances (i.e., > 5–10 m depending on size) may simply be marked with a generic fish identification term, “teleost.”

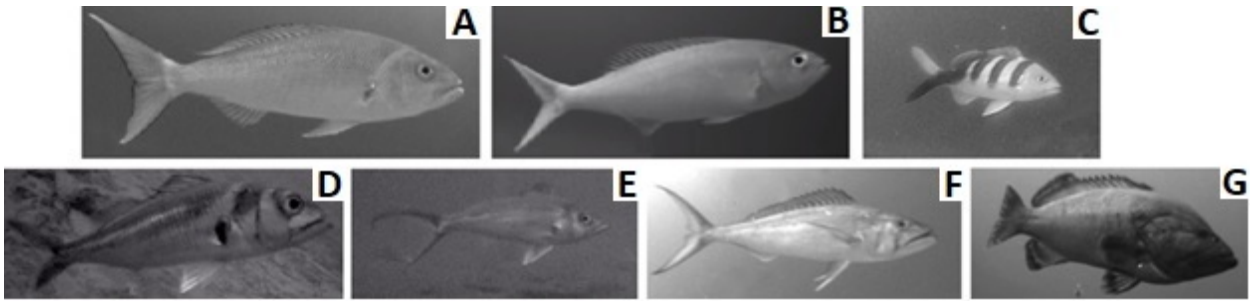

Figure 5.1 MOUSS camera observations of Deep 7 bottomfish: (A) *Pristipomoides filamentosus*, (B) *Pristipomoides sieboldii*, (C) *Pristipomoides zonatus*, (D) *Etelis carbunculus*, (E) *Etelis coruscans*, (F) *Aphareus rutilans*, and (G) *Hyporthodus quernus*.

As analysts review a video, each unique target fish species is marked with a point for “time of first arrival” (TOFA). For each target fish species, another point is used to mark the maximum observed count in a single frame of view, or “MaxN.” Non-target fish species are marked with a point to indicate presence the first time they are encountered, but counts and lengths are not recorded.

The PIFSC video analysts use “MaxN,” the maximum observed count of a fish species in a single frame of view, as a conservative minimum estimate of fish abundance for target fish species. MaxN has been widely used in underwater camera studies for relative abundance of fishes (Ellis and DeMartini 1995, Willis et al. 2000, Cappo et al. 2006, Merritt et al. 2011, Asher et al. 2017). The use of MaxN ensures that individual fish are not re-counted (i.e., as they

repeatedly leave and re-enter the video's field of view), although it may underestimate true fish abundance if individuals arrive and leave in a staggered fashion so that maximum number is always lower than the total number of fish that were attracted to the bait (Misa et al. 2016). It is also possible that uncommon or rare species could remain undetected if they pass behind the MOUSS. Abundance estimates can also be affected when the field of view becomes saturated with fish (i.e., if a large school takes up all available view space).

Once MaxN is determined for the 15-minute analysis period, fish length measurements are generated for all individuals at the time of MaxN for each target species. Measuring fish at the time of MaxN may potentially result in sizing biases, i.e. selecting smaller schooling fish while missing smaller numbers of larger individuals (Willis et al. 2003). Finally, while only one video is required for initial fish identification and MaxN counts, both left and right videos are required to generate length measurements.

Stereo-video methods and specialized software allow for highly accurate (i.e. within 1% of the true fish length) and precise measurements of fish at a range of up to 10 m, depending on fish size and image quality (Harvey and Shortis 1998, Shortis et al. 2009, Harvey et al. 2010). Larger fish can be accurately measured at a greater distance, though most measurements of Hawaiian bottomfish occur from 1 to 4 m of the camera. Fish are measured from the tip of the snout to the caudal center fork (fork-length) to generate size-frequency estimates for fisheries stock assessments.

Along with proper stereo-video calibration techniques, a favorable fish orientation is vital to generate accurate and precise length measurements (Harvey et al. 2002). To measure each fish individual belonging to a target bottomfish species, video analysts begin at the time of MaxN. Analysts then manually play the video forward or backward (i.e., "frame stepping") until the fish is in a favorable orthogonal (or near-orthogonal) orientation with the snout and caudal fork clearly visible in both left and right stereo-video frames (Figure 5.2). The Euclidean distance from snout to tail changes as the fish swims, therefore video analysts should select frames where the fish body appears to be straight or minimally distorted (Shortis et al. 2013). Once a frame with the fish in a favorable orientation has been identified, the video analyst uses EventMeasure™ to compute the fish length by clicking on the tip of the fish's snout in the left video frame followed by the tip of the snout in the right frame, then the center caudal fork in the left video frame followed by the caudal fork in the right frame. The software automatically computes and records the fork length measurement for that frame.

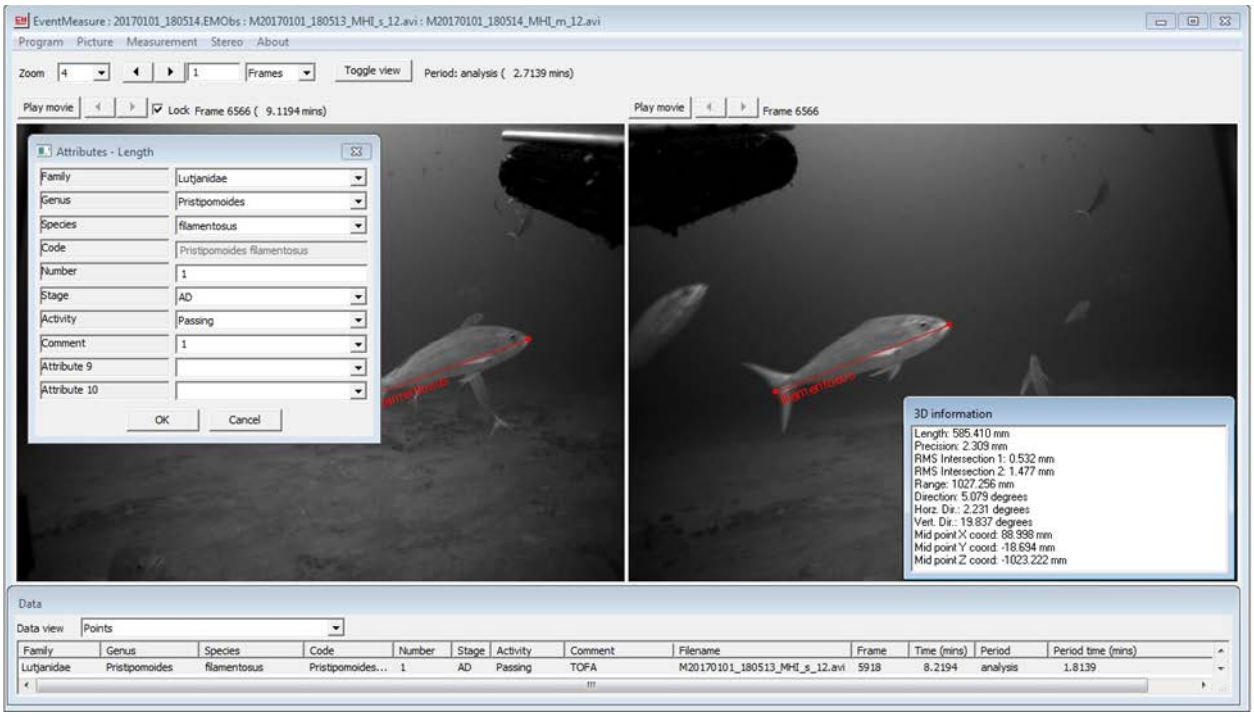

Figure 5.2 Screengrab of EventMeasure™ software showing *Pristipomoides filamentous* at a frame with an ideal body orientation for fork-length measurement.

To further improve measurement precision, three replicate length measurements are taken on different frames; however, two measurements are acceptable in cases where only two frames are available or when two measurements are more accurate (e.g., when the individual has an unfavorable curved body orientation in all other possible frames). The analyst frame steps the video forward or backwards as needed, tracking the fish from the time of MaxN ensuring the individual being measured does not leave the frame. Occasionally a fish individual may be impossible to measure (e.g., remains at an extreme distance from the camera; is obscured; or appears only partially on screen in one or both stereo-videos). In these cases, the analyst marks the fish with a "3-D point" to calculate the fish range to the camera. For complete step-by-step video annotation protocols, see Appendix E: MOUSS Video Annotation.

6. Integration of New Technologies

The MOUSS operates with an 82° field of view (FOV), and at present, it is unknown whether or not relative abundances are underestimated due to fish remaining outside the FOV of the stereo-cameras. To explore this question, NOAA PIFSC researchers developed the “Moana-360”. The Moana-360 is a 360° camera-housing system employed as a supplemental technology to compare fish abundance estimates between directional and omnidirectional systems. The MOUSS is currently limited to ambient light surveys to 250 m, while Deep 7 bottomfish can occur well beyond such depths. In an effort to address this gap, NOAA PIFSC researchers tested acoustic imaging technologies, including the Dual-frequency Identification Sonar (DIDSON), to assess fish identification capabilities for potential use at deeper depths. Recently, in 2018, NOAA PIFSC began collecting water-column environmental deoxyribonucleic acid (eDNA) samples paired with MOUSS and Moana-360 optical data to better evaluate the utility of this emerging technology and to compare bottomfish optical vs. genetic detectability. This section describes these ancillary technologies and their use at the PIFSC.

6.1 360° Imaging

The majority of camera systems used for fisheries-independent surveys incorporate unidirectional, limited FOV that may lead to erroneous species abundance estimates (i.e., underestimating abundance of large schools; missing rare species; Grasty and Campbell 2019). In addition, the use of baited camera survey designs have caused concern among some researchers, since the area over which the bait attracts fish to the camera, and therefore the sampling area represented by each camera deployment, remains unknown (Harvey et al. 2013, Ault et al. 2018). Finally, researchers have also questioned the true accuracy of fish abundance estimates because the number of fish outside the camera FOV remains unknown.

To better define these uncertainties and compare systems with varying FOVs, 360° cameras were deployed paired with the MOUSS. To successfully accomplish these comparisons, the universal “Moana-360” underwater camera housing system (Figure 6.1 A) was developed. This housing is compatible with most low-cost, off-the-shelf 360° cameras and retains the same 500-m maximum depth rating as the MOUSS.

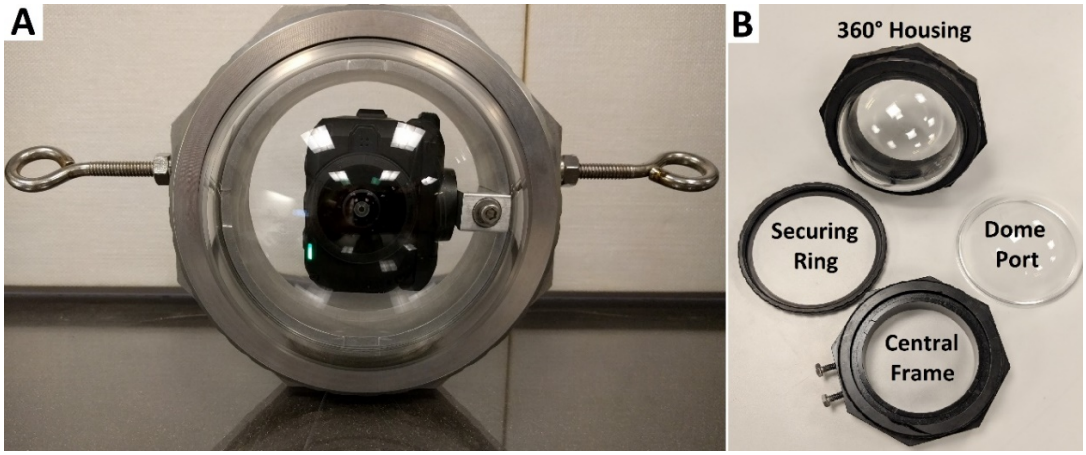

Figure 6.1 (A) The Moana-360 complete system with a Garmin VIRB 360 camera mounted inside and (B) the modular housing components.

The Moana-360 housing features a modular design utilizing two off-the-shelf acrylic 11.43 cm dome ports. The housing components include a central frame, two dome ports, two O-rings (not shown), and two securing rings (Figure 6.1 B). This simple design easily accommodates various low-cost off-the-shelf 360° cameras, with internal camera mounts specific to each camera type. Each internal camera mount was designed so that the camera lens is centered in the dome port to minimize image distortion. In the summer of 2017, six popular consumer-grade 360° cameras with prices ranging from $140 to $1,130 USD were compared (Figure 6.2; Table 6.1). Two of these were hemispheric in design (360 Fly and Kodak PIXPRO 4k) and paired to create a 360° view, and four were true 360° camera systems (Nikon KeyMission 360, EleCam 360, Garmin VIRB 360, and Samsung Gear 360).

Figure 6.2 Six popular consumer grade 360° cameras.

Four Moana-360s were mounted inside the MOUSS frame to compare 360° camera types (Figure 6.3), along with a CTD and TDRs for depth measurements during field testing. Cameras were compared based on ease of field use, software utility and remote functions, battery duration and ease of replacement, video data storage capacity, and upgrade options (Table 6.1). The Garmin VIRB 360 camera was identified as the preferred 360° camera option for use with the Moana-360 housing for 360°-video research at PIFSC, primarily due to its ease of use in the field (particularly on small boats), internal GPS, easily swappable battery and SD cards, and software functions.

Table 6.1 Comparison of 360° camera models.

360 Camera Model	FOV	Price	Video Resolution	fps	Remote	Data Storage (micro SD)	Battery Life	Advantages	Disadvantages
Garmin VIRB 360	360°	$660	3840 × 2160	30	Yes; Can use GPS unit	External (128 GB)	External, 1 h	Easy to use in field; GPS capability	Somewhat bulky
Kodak PIXPRO 4k	360° × 235° lens	$1130	2880 × 2880	30	Yes, remote included	External	External, < 1 h	Two separate cameras; Includes accessories	2 videos stitched w/ software for 360°
Samsung Gear 360	360°	$300	3840 × 1920	24	Yes, sold separately	External	External	Compact design; Inexpensive	Samsung phone or software required
360 Fly	360° × 240° lens	$1070	2880 × 2880	24	No	Internal (64 GB)	Internal, 1.5 h	Two separate cameras	Internal data storage and battery
Nikon KeyMission 360	360°	$615	3840 × 1920	24	Yes	External	External, 1 h	Rugged, compact design	Software/settings difficult to use
EleCam 360	360°	$140	1920 × 1080	30	No	External (32 GB)	Internal, 1 h	Inexpensive	Camera freezes; Internal battery

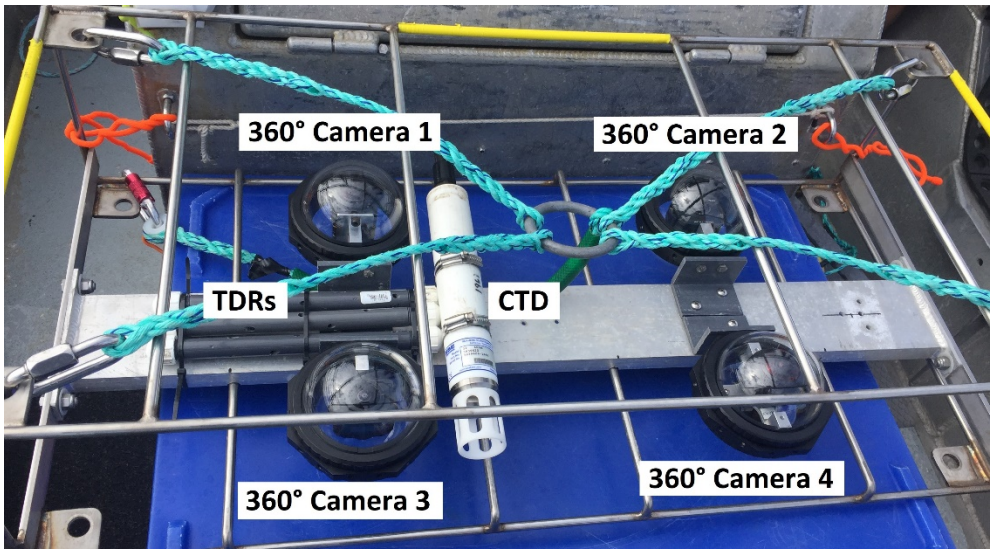

Figure 6.3 Field testing design with four Moana-360 housings mounted inside a MOUSS frame with a CTD and TDRs to compare four different off-the-shelf 360° cameras.

The Moana-360 currently ranks among the deepest-rated and most affordable 360° camera systems developed (i.e. $15,000 USD for an off-the-shelf Boxfish™ 360 versus less than $2,000 USD for Moana-360). Beginning in fall 2018, PIFSC used the Moana-360 omnidirectional camera system paired with the MOUSS to compare fish detection capabilities between camera systems. PIFSC researchers are currently annotating these videos for abundance/diversity measures to assess whether fishes may be missed when MaxN abundance estimates are generated using the MOUSS's directional camera design and limited 82° FOV.

6.2 Acoustic Imaging

As previously described, effective MOUSS sampling remains contingent on available ambient light down to 250 m; however, Deep 7 bottomfish can be found well-below that limit (e.g., *Etelis coruscans* to 400 m; Kelley and Moriwake 2012). In Hawaii, the Gulf of Mexico and California, the MOUSS was augmented with DIDSON acoustic imaging sonar module for comparison of optical and acoustic signatures of target fish taxa. The DIDSON uses sonar to produce video-like images of fish in waters too dark or turbid for traditional ambient light-based video methods (Martignac et al. 2015), and may be useful for deeper waters and data collection at night. PIFSC researchers assessed the suitability and compatibility of the DIDSON acoustic "camera" as a potential method to collect bottomfish data to extend fishery-independent sampling beyond the limitations of ambient light stereo-video.

The MOUSS and DIDSON were compared in a side-by-side reef fish detection capabilities experiment at the Hawaii Institute of Marine Biology (HIMB) research facility on Coconut Island, Oahu. The MOUSS system was mounted inside a sturdy camera frame (Figure 6.4) with the DIDSON mounted above the frame facing forward to give a similar field of view as the right side MOUSS camera. A BlueView imaging sonar was also mounted on the frame, however it did not produce useful imagery, thus the BlueView data was not analyzed.

Figure 6.4 Configuration of the MOUSS-DIDSON inter-comparison study with the MOUSS mounted inside the frame, DIDSON mounted on top left, and BlueView (data not used) mounted on the top right of the frame.

Optical and acoustic camera data were collected in April 2017 from the Coconut Island water taxi dock. A bait bag was used to attract fish to the area, and the refill time (where the bag was reloaded with fresh bait once the previous bag was exhausted) was used as a "sync" point to synchronize analysis periods for each method. Five 5-minute observation periods were analyzed, two before and three after the sync point, for a 25-minute experiment time. It was assumed that

fish attracted to the area would generally remain onsite for the duration of the experiment. All fish were counted as they moved across a mid-point from left to right (Figure 6.5), and fish range (m) was measured for both DIDSON and MOUSS. Additionally, all fish were identified to the lowest taxonomic level possible and fish length (mm) was measured whenever possible.

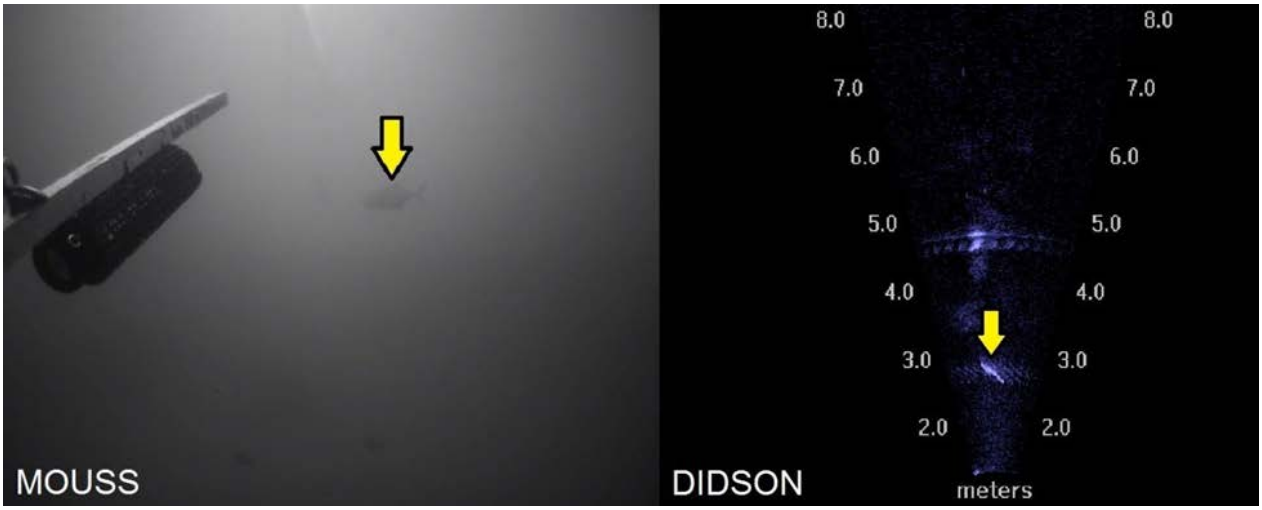

Figure 6.5 Screengrabs of the same fish (yellow arrow), as captured by the MOUSS (left panel) and the DIDSON (right panel).

A total of 111 (MOUSS) and 53 (DIDSON) fish observations were detected by each respective method (Table 6.2). The difference in number of fish observations may be at least partially explained by the existence of a "blind spot" known in the DIDSON community, where fish within less than a 1.3 m range from the instrument were not detected. In addition, the DIDSON is typically unable to detect very small fish (< 5 cm; Martignac et al. 2015), which (in conjunction with the blind spot) may help explain why the DIDSON generated a larger mean fish size versus the MOUSS (Table 6.2). The mean range of detection was noticeably higher for the DIDSON (up to 4.6 m) compared with the MOUSS (2.6 m maximum) due water turbidity. Finally, the MOUSS identified five different taxa of fish (Table 6.3), with 28% of observations identified only to the genus level and 41% identified to the species level. The DIDSON was unable to provide sufficient image detail at any taxonomic level.

Table 6.2 Fish count, mean size (mm), number of measurements taken, and mean fish range (m) for the MOUSS and DIDSON for each of five replicate 5-minute analyses.

	Fish Count		Mean Size (mm)		# Measurements		Mean Range (m)	
5-min	**MOUSS**	**DIDSON**	**MOUSS**	**DIDSON**	**MOUSS**	**DIDSON**	**MOUSS**	**DIDSON**
1	3	0	200.3	n/a	3	0	1.4	n/a
2	32	21	255.4	337.6	7	21	2.6	4.6
3	20	7	349.1	426.0	6	7	2.3	3.2
4	29	6	322.5	454.7	5	6	2.6	2.8
5	27	19	258.7	368.5	5	19	2.4	3.7
Overall	**111**	**53**	**277.2**	**396.7**	**26**	**53**	**2.3**	**3.6**

Table 6.3 Fish observations by taxonomic level for the MOUSS and the DIDSON.

	MOUSS	DIDSON
Total # Observations	111	53
Acanthurus blochii	14	
Acanthurus sp.	28	
Caranx melampygus	31	
Lutjanus kasmira	1	
Abudefduf sp.	3	
Teleost (unable to ID fish)	34	53
Percent Observations	%	%
Unable to ID fish	30.6	100
ID to genus level only	27.9	
ID to species level	41.4	

Overall, results indicated that the DIDSON could provide basic fish length and abundance estimates; however, species-level identifications were not possible. This represents a significant disadvantage compared to optical survey methods (particularly in cases where bottomfish form mixed-species assemblages), given fisheries and stock assessment scientists rely on species-specific fish abundance estimates. Additionally, the DIDSON's limited FOV and cost[2] would make it impractical for large-scale fisheries surveys. In summary, the DIDSON is not appropriate for stand-alone Deep 7 bottomfish surveys, and should only be used as an ancillary research tool until the technology improves.

6.3 eDNA Sampling

Environmental DNA (eDNA) is a new fishery-independent bio-assessment tool that can potentially improve fish species detection (Jerde et al. 2019). NOAA PIFSC developed a programmable timed release water sampler called the Ossolinski Actuator (OA; named for one of the developers), to collect water samples up to 500 m. The OA consists of two components: 1) a standard Niskin water-sampling bottle, and 2) a custom-built programmable electronic time-release device (Figure 6.7). The release device is modular in design and can be used with various size (volume) Niskin water-sampling bottles. The time release mechanism is equipped with a 12-volt programmable relay (0 to 999 minutes) and a linear actuator inside a billet aluminum housing. The time release is designed to replace the Niskin bottle closure and trigger mechanisms, and uses the existing latex bungee and monofilament loop setup, requiring minimal to no adjustments. The sampling bottle is armed by opening both end caps with the latex bungees held under tension (Figure 6.6 A). While under tension, the monofilament loops are placed over the extended actuator rod and secured (Figure 6.6 B). The OA is then armed and ready to be deployed. Immediately prior to deployment, the pre-programmed relay timer is turned "ON" and the countdown begins. Once the desired sampling time is reached (underwater) the actuator rod retracts, rapidly closing the Niskin bottle end caps to collect the water sample.

[2] http://www.soundmetrics.com/

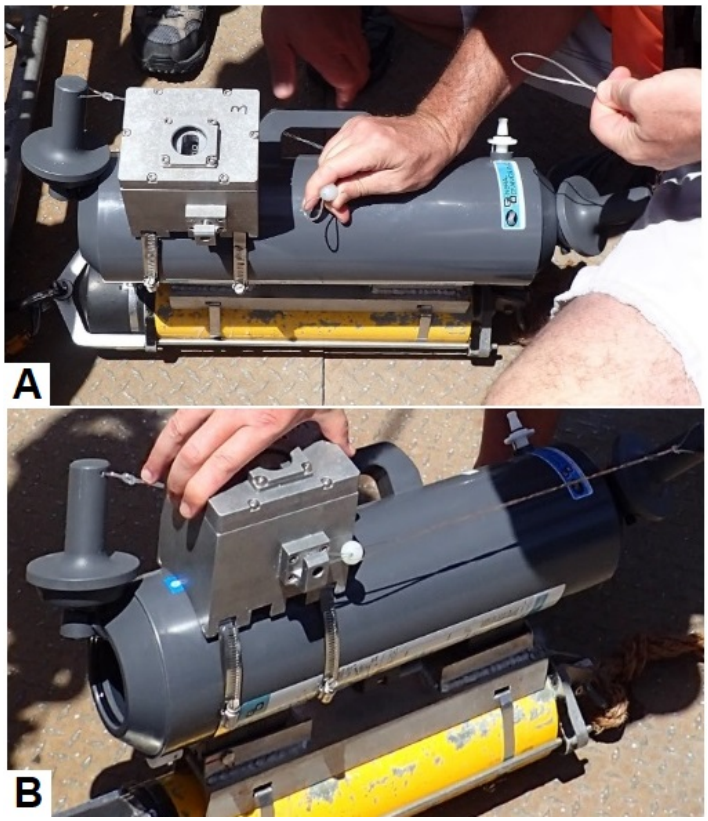

Figure 6.6 The Ossolinski Actuator with Niskin water sampling bottle and time-release device (metal box), showing (A) bottle end caps opened under tension and (B) bottle armed with monofilament secured by the actuator rod.

The OA was used during BFISH surveys in October 2018, June 2019, and September 2019, to collect eDNA samples paired with MOUSS video sampling to confirm (or refute) the ability of eDNA sampling methods to detect the presence of bottomfish. The OA was mounted below the MOUSS cameras, attached to an acoustic release with a custom bracket and hose clamps (Figure 6.7 B). Following video capture, the OA time release closed the Niskin bottle to collect the water sample at camera depth, and the sample was brought back to the ship for eDNA processing upon MOUSS retrieval.

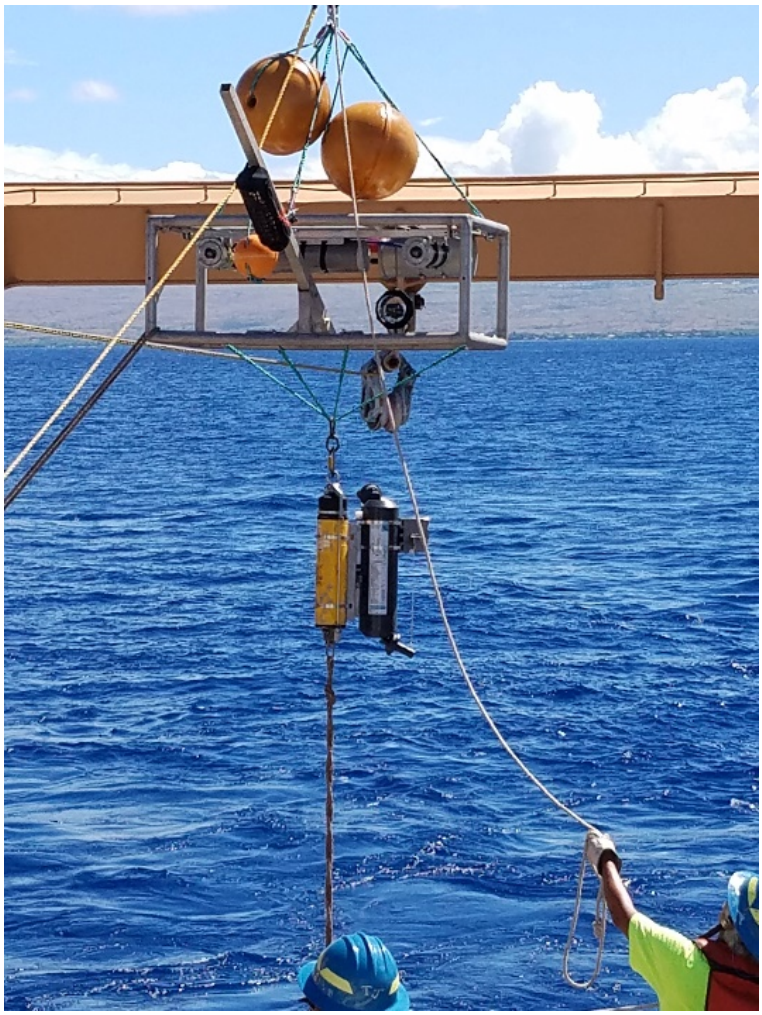

Figure 6.7 The MOUSS, Moana-360 (inside frame) and Ossolinski Actuator (attached to acoustic release) immediately before deployment from the NOAA Ship *Oscar Elton Sette*.

During 2018–2019 BFISH survey operations, the MOUSS, Moana-360, and OA were deployed to collect stereo-video, 360° video, and eDNA samples (Figure 6.7), with a total of 110 deployments. Further data collections are planned for FY2020 while data analyses remain ongoing.

Acknowledgements

The development of the Modular Optical Underwater Survey System (MOUSS) was funded by NOAA's Pacific Islands Fisheries Science Center and the NOAA Fisheries Office of Science and Technology. The authors would like to thank Jeffery Drazen for helpful review of this manuscript, and everyone involved with the MOUSS project since its inception, particularly Michael Seki, Annie Yau, Benjamin Richards, and Noriko Shoji. The authors would also like to thank the many individuals involved with field testing, deployment, and data analysis, including Audrey Rollo, Chris Demarke, William Misa, Justin Ossolinski, James Barlow, Rory Driskell, Louise Giuseffi, David McVay, Kelli-Ann Bliss, Kristin Raja, Laura Rock, Kevin O'Brien, Tate Wester, Erin Reed, Mark Nadon, Kyle Koyanagi, Russell Reardon, Jesse Abdul, Jeff Anderson, Hanumant Singh, Grace Young, and Jeremy Childress. The authors also wish to thank the officers and crew of NOAA Ship *Oscar Elton Sette* and the crew of the *Ao Shibi IV* for their assistance during field deployments. The findings and conclusions in this paper are those of the authors and do not necessarily represent the views of NOAA Fisheries. The use of trade, firm, or corporation names in this publication is for the convenience of the reader and does not constitute an official endorsement or approval of any product or service to the exclusion of others that may be suitable.

Literature Cited

Amin R, Richards BL, Misa WFXE, Taylor, JT, Miller DR, Rollo AK, Demarke C, Singh H, Young GC, Childress J, Ossolinski JE, Reardon RT, Koyanagi KH. 2017. The modular optical underwater camera survey system. Sensors. 17 (2309), 14 p.

Andrews AH, DeMartini EE, Brodziak J, Nichols RS, Humpreys R. 2012. A long-lived life history for a tropical, deepwater snapper (*Pristipomoides filamentosus*): bomb radiocarbon and lead-radium dating as extensions of daily increment analyses in otoliths. Candaian J Fish Aqua Sci. 69, p. 1850–1869.

Asher J, Williams ID, Harvey ES. 2017. Mesophotic depth gradients impact reef fish assemblage composition and functional group partitioning in the main Hawaiian Islands. Front Mar Sci. 4 (98), 18 p.

Ault JS, Smith SG, Richards BL, Yau AJ, Langseth BJ, O'Malley JM, Boggs CH, Seki MP, DiNardo GT. 2018. Towards fishery-independent biomass estimation for Hawaiian Islands deepwater snappers. Fish Res. 208, p. 321–328.

Bouguet JY. 2004. Camera Calibration Toolbox for Matlab. Available online: http://www.vision.caltech.edu/bouguetj/calib_doc/

Boutros N, Shortis MR, Harvey ES. 2015. A comparison of calibration methods and system configurations of underwater stereo-video systems for applications in marine ecology. Limnol Oceanogr. 13, p. 224–236.

Brodziak J. 2007. An investigation of alternative production models to assess the Hawaiian bottomfish complex. Pacific Islands Fisheries Science Center, National Marine Fisheries Service, NOAA, Honolulu, Hawaii, USA. PIFSC Administrative Report H-07-01, 63 p.

Brodziak J, Courtney D, Wagatsuma L, O'Malley J, Lee H-H, Walsh W, Andrews A, Humpreys R, DiNardo G. 2011. Stock assessment of the main Hawaiian Islands Deep-7 bottomfish complex through 2010. U.S. Department of Commerce, NOAA Tech Memo, NOAA-TM-NMFS-PIFSC-29. 176 p. + Appendix.

Cappo M, Harvey ES, Shortis M. 2006. Counting and measuring fish with baited video techniques -an overview. In: Proceedings of the Australian Society for Fish Biology Workshop, Hobart, Australia, 28–29 August, 2006, p. 101–114.

Clarke TA, Fryer JG. 1998. The development of camera calibration methods and models. Photogramm Rec. 16, p. 51–66.

Drazen JC, Moriwake V, Sackett D, Demarke C. 2014. Evaluating the effectiveness of restricted areas for improving the bottomfish fishery in the main Hawaiian Islands. Final report to State of Hawaii, Division of Aquatic Resources. 33 p.

Ellis DM, DeMartini EE. 1995. Evaluation of a video camera technique for indexing the abundances of juvenile pink snapper, *Pristipomoides filamentosus*, and other Hawaiian insular shelf fishes. Fish Bull. 93, p. 67–77.

Grasty SE, Campbell MD. 2019. Understanding and quantifying bias in visual fisheries surveys using advanced technology. Fish. 44(5), p. 212–215.

Haight WR, Kobayashi DR, Kawamoto KE. 1993. Biology and management of deepwater snappers of the Hawaiian Archipelago. Mar Fish Rev. 55, p. 20–27.

Harvey E, Shortis M. 1995. A system for stereo-video measurement of sub-tidal organisms. Mar Technol Soc J. 29(4), p. 10–22.

Harvey ES, Shortis MR. 1998. Calibration stability of an underwater stereo video system: implications for measurement accuracy and precision. Mar Technol Soc J. 32, 3–17.

Harvey E, Fletcher D, Shortis M. 2002. Estimation of reef fish length by divers and by stereo-video: a first comparison of the accuracy and precision in the field on living fish under operational conditions. Fish Res. 57, p. 255–265.

Harvey E, Goeyze J, McLaren B, Langlois TJ, Shortis M. 2010. Influence of range, angle of view, image resolution and image compression on underwater stereo-video measurements: high definition and broadcast resolution video cameras compared. Mar Technol Soc J. 44, p. 1–11.

Harvey ES, McLean D, Haywood MDE, Newman SJ, Williams A. 2013. The use of BRUVs as a tool for assessing marine fisheries and ecosystems: a review of the hurdles and potential (2011 National Workshop). Fisheries Research and Development Corporation, Australia; The University of Western Australia Project No. 2010/22. 202 p.

Jerde CL, Wilson EA, Dressler TL. 2019. Measuring global fish species richness with eDNA metabarcoding. Mol Ecol Resour. 19, p. 19–22.

Kelley C, Moffitt R, Smith JR. 2006. Mega- to micro-scale classification and description of bottomfish essential fish habitat on four banks in the Northwestern Hawaiian Islands. Atoll Res Bull. 543, p. 319–332.

Kelley CD, Moriwake VN. 2012. Appendix 3: essential fish habitat descriptions, part 1: bottomfish. In: WPRFMC (Ed.) Final fishery management plan for coral reef ecosystems of the western Pacific region III. Essential fish habitat for management unit species, p. 597.

Langlois TJ, Fitzpatrick BR, Fairclough DV, Wakefield CB, Hesp SA, McLean DL, Harvey ES, Meeuwig JJ. 2012. Similarities between line fishing and baited stereo-video estimations of length-frequency: novel application of kernel density estimates. PLOS ONE, 7(11), 9 p. Available online: https://doi.org/10.1371/journal.pone.0045973

Langseth B, Syslo J, Yau A, Kapur M, Brodziak J. 2018. Stock assessment for the main Hawaiian Islands Deep 7 bottomfish complex in 2018, with catch projections through 2022. U.S. Department of Commerce, NOAA Tech Memo, NMFS-PIFSC-69, 217 p.

Magnuson-Stevens Fishery Conservation and Management Act. 2007. 16 U.S.C. 1801.

Mallet D, Pelletier D. 2014. Underwater video techniques for observing coastal marine biodiversity: A review of sixty years of publications (1952–2012). Fish Res. 154, p. 44–62.

Martignac F, Daroux A, Bagliniere J, Ombredane D, Guillard J. 2015. The use of acoustic cameras in shallow waters: new hydroacoustic tools for monitoring migratory fish population. A review of DIDSON technology. Fish Fish. 16, p. 486–510.

Merritt DW, Donovan MK, Kelley C, Waterhouse L, Parke M, Wong K, Drazen JC. 2011. BotCam: A baited camera system for non-extractive monitoring of bottomfish species. Fish Bull. 109, p. 56–67.

Misa WFXE, Drazen JC, Kelley CD, Moriwake VN. 2013. Establishing species–habitat associations for 4 eteline snappers with the use of a baited stereo-video camera system. Fish Bull. 111, p. 293–308.

Misa WFXE, Richards BL, Moriwake VN, Kelley C, Drazen JC, Dinardo G. 2016. Evaluating the effect of soak time on bottomfish abundance and length data from stereo-video surveys. J Exper Mar Biol Ecol. 479, p. 20–34.

Misa WFXE, Amin R, Asher JM, Richards BL, Taylor JT, Rollo AK, Miller DM, Demarke C. 2020. BotCam to MOUSS: Comparative tests on bottomfish relative abundance, length data, and imagery generated by 2 stereo-camera systems during field surveys in Hawaii. U.S. Department of Commerce, NOAA Tech Memo, NOAA-NMFS-PIFSC-94, 26 p.

Moffitt R, Kobayashi D, DiNardo G. 2006. Status of the Hawaiian bottomfish stocks, 2004. Pacific Islands Fisheries Science Center, National Marine Fisheries Service, NOAA, Honolulu, Hawaii, USA. PIFSC Internal Report IR-11-003, 134 p.

Moore CH, Drazen JC, Kelley CD, Misa WFXE. 2013. Deepwater marine protected areas of the main Hawaiian Islands: establishing baselines for commercially valuable bottomfish populations. Mar Ecol Progr Ser. 476, p. 167–183.

Murphy HM, Jenkins GP. 2010. Observational methods used in marine spatial monitoring of fishes and associated habitats: a review. Marine and Freshwater Research. 61, p. 236–252.

Oyafuso ZS, Drazen JC, Moore CH, Franklin EC. 2017. Habitat-based species distribution modelling of the Hawaiian deepwater snapper-grouper complex. Fisheries Research. 195, p. 19–27.

Parke M. 2007. Linking Hawaii fishermen reported commercial bottomfish catch data to potential bottomfish habitat and proposed restricted fishing areas using GIS and spatial analysis. U.S. Department of Commerce NOAA Tech Memo, NOAA-TM-NMFS-PIFSC-11. 37 p.

Parrish FA, DeMartini EE, Ellis DM. 1997. Nursery habitat in relation to production of juvenile pink snapper, *Pristipomoides filamentosus*, in the Hawaiian Archipelago. Fish Bull. 95, p. 137–148.

Ralston S, Polovina JJ. 1982. A multispecies analysis of the commercial deep-sea handline fishery in Hawaii. Fish Bull. 80, p. 435–448.

Ralston S, Cox S, Labelle M, Mees C. 2004. Bottomfish stock assessment workshop. Final panel report to Western Pacific Fishery Management Council. 20 p. Available online: http://www.wpcouncil.org/wp-content/uploads/2017/12/PanelReport.pdf

Richards BL, Smith SG, Ault JS, DiNardo GT, Kobayashi D, Domokos R, Anderson J, Taylor J, Misa W, Giuseffi L, Rollo A, Merritt D, Drazen JC, Clarke ME, Tam C. (2016). Design and implementation of a bottomfish fishery-independent survey in the main Hawaiian Islands. U.S. Department of Commerce, NOAA Tech Memo, NOAA-TM-NMFS-PIFSC-53, 54 p.

Sackett DK, Drazen JC, Moriwake VN, Kelley CD, Schumacher BD, Misa WFXE. 2014. Marine protected areas for deepwater fish populations: An evaluation of their effects in Hawaii. Mar Biol. 161, p. 411–425.

Sackett D, Kelley CD, Drazen JC. 2017. Spilling over deepwater boundaries; evidence of spillover from two deepwater protected areas in Hawaii. Mar Ecol Progr Ser. 568, p. 175–190.

Seager J. 2008. SeaGIS CAL and Photomeasure stereo photogrammetric calibration and analysis software. http://seagis.com.au

Shortis MR, Harvey ES, Abdo DA. 2009. A review of underwater stereo-image measurement for marine biology and ecology applications. In: Gibson RN, Atkinson RJA, and Gordon JDM (Eds.) Oceanography and Marine Biology: an annual review. 47. CRC Press, Boca Raton, FL, USA. 342 p.

Shortis MR, Ravanbakskh M, Shaifat F, Harvey ES, Mian A, Seager JW, Culverhouse PF, Cline DE, Edgington DR. 2013. A review of techniques for the identification and measurement of fish in underwater stereo-video image sequences. In: Proceedings of the SPIE Optical Metrology 2013, Munich, Germany. 23 May, 2013, 8791, p. 87910G.

State of Hawaii. 2010. Hawaii Administrative Rules 13-94. Protected Marine Fisheries Resources, Bottomfish Management. Department of Land and Natural Resources. 14 p. Available online: https://dlnr.hawaii.gov/dar/files/2014/04/ch94.pdf

Western Pacific Regional Fishery Management Council. 2010. Bottomfish fisheries in the Hawaiian Archipelago. Fact sheet, 2 p. Available online: http://www.wpcouncil.org/education/docs/Bottomfish%20Fisheries%20in%20the%20Hawaii%20Archipelago%20Fact%20Sheet%202010.pdf

Western Pacific Regional Fishery Management Council. 2019. Annual Stock Assessment and Fishery Evaluation Report for the Hawaii Archipelago Fishery Ecosystem Plan 2018. Remington T, Sabater M, Ishizaki A, and Spalding S (Eds.) Honolulu, Hawaii 96813 USA. 217 p. + Appendices.

Willis TJ, Millar RB, Babcock RC. 2000. Detection of spatial variability in relative density of fishes: comparison of visual census, angling and baited underwater video. Mar Ecol Progr Ser. 198, p. 249–260.

Willis TJ, Millar RB, Babcock RC. 2003. Protection of exploited fish in temperate regions: high density and biomass of snapper *Pargrus auratus* (Sparidae) in northern New Zealand marine reserves. J Appl Ecol. 40(2), p. 214–227.

Appendix A: MOUSS Calibration Protocol

The complete step-by-step protocol for MOUSS stereo-video camera calibration using SeaGIS CAL (version 3.21) and EventMeasure™ software (version 5.25), is as follows:

The files needed to begin each new video calibration include:

- Camera calibration starter files: *MOUSS_left_starter.CamCAL*
  MOUSS_right_starter.CamCAL
- Calibration cube files: *Cube two stripe.PtsCAL*
  Object space distances cube 2.txt
- Calibration history spreadsheet: *Calibration history.xls*

These are example video files for the MOUSS cameras being calibrated:

- Video files (slave/left): *M20170101_180513_MHI_s_12.avi*
  (master/right): *M20170101_180514_MHI_m_12.avi*

See section 5.1 MOUSS Video File Name Convention, for full explanation of file naming conventions.

Setup

1. File organization requirements

a. Within the Calibration folder, create a folder with the camera calibration date (e.g., YYYYMMDD) as the folder name (e.g., 20170101_cal) and create individual subfolders by MOUSS frame for each frame being calibrated (e.g., MOUSS_01_20170101).

b. Copy and place the camera calibration, cube calibration, and calibration video files in their respective subfolders. Refer to the MOUSS information slate shown at beginning of the calibration video to find the MOUSS frame letter (play video in VLC media player).

The starting camera calibration files and cube calibration files are the same for all MOUSS units. Always ensure that original versions are copied from the Calibration files folder to each MOUSS unit subfolder as these files get edited during the calibration process.

2. Open CAL software and setup a new project

a. Project → New Project → Select name for NEW project file → OK → Locate appropriate subfolder within the YYYYMMDD_cal folder → Enter a calibration project file name same as subfolder name (e.g., MOUSS_01_20170101) in File name field → Save

b. Uncheck the “Lock” box next to frame step controls

c. Select the left camera file → OK → *MOUSS_left_starter.CamCAL* → Open

d. Select the right camera file → OK → *MOUSS_right_starter.CamCAL* → Open

e. Select the calibration cube file → OK → *Cube two stripe.PtsCAL* → Open

f. Set the picture directory → OK → Browse for folder (e.g., Calibration → 20170101_cal → MOUSS_01_20170101) → OK

g. Save the measurement file → OK → Enter an orientation and observation file name same as subfolder name (e.g., MOUSS_01_20170101) in File name field → Save

h. Load the left picture (and add to left movie sequence) → OK → Select slave camera video (e.g., *M20170101_180513_MHI_s_12.avi*) → Open

Movie sequence configuration → OK

i. Load the right picture (and add to right movie sequence) → OK → Select master camera video (e.g., *M20170101_180514_MHI_m_12.avi*) → Open

Movie sequence configuration → OK

j. Current project files → Double-check that all necessary calibration and video files have been loaded then → Close dialog

k. Check the "Lock" box next to the frame step controls → Play left camera video until first hand sync action is seen → Hit "Close player and update position" → Uncheck the "Lock" box and make frame adjustments to match left and right camera images (if needed) then re-check the "Lock" box

Calibration

1. Point selection

a. Picture → Adjust brightness and contrast → Adjust the brightness and contrast until the white points on the calibration cube appear clearest.

The brightness and contrast box may need to be moved to where it does not block the view of either video; closing the brightness and contrast box will reset the brightness and contrast settings applied.

b. Measurement → Edit centroid parameters → Check that "Window Size" = 10, "Maximum Pixel Intensity Range" = 15, "Maximum Target Size" = 2, and "X to Y Ratio" = 0.15 → OK

c. Play the left camera video until just before the start of the calibration cube positional orientations/rotations are being done and point 100 is on the upper-left side of the forward-facing calibration cube as seen below (Figure A.1)→ Select "Close player and update position"

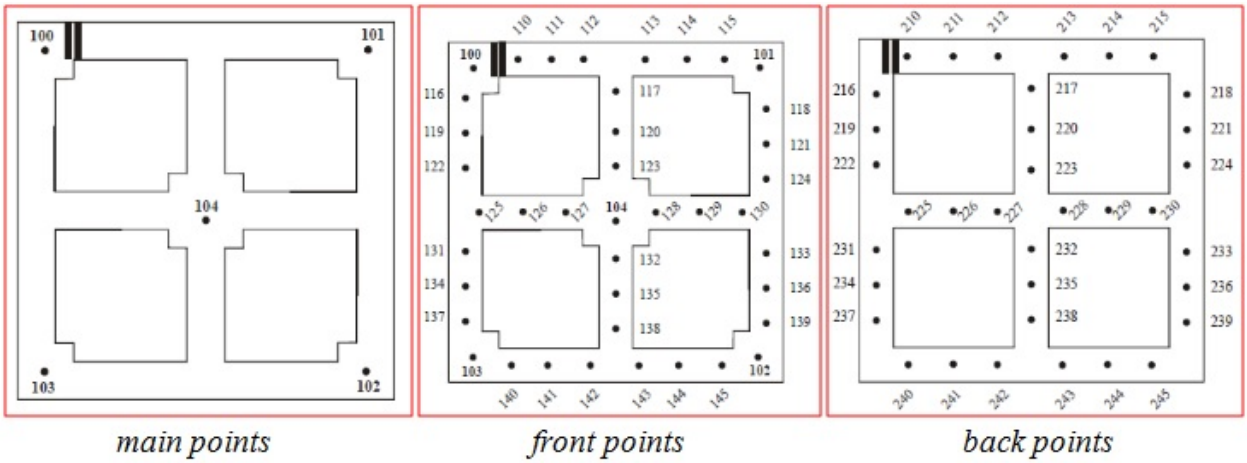

Figure A.1 Numbered main points, front points, and back points on the calibration cube.

d. Use the centroiding function (hold down "Shift") to select cube point 100 in the left camera video by placing the centroiding box over the point then left-clicking → Do the same for points 101, 102, and 103 → Select points 100, 101, 102, and 103 in the right camera video again using the centroiding function → All other calibration cube points, seen in the figure above, should self-populate.

Always select the main points in clock-wise order (100 to 103).

e. The calibration cube will be positioned in five orientations: forward-facing; tilted forward; tilted back; angled to the left; angled to the right. These 5 orientations are done with point 100 in four different locations: upper-left corner; upper-right corner; lower-right corner; lower-left corner. A single 90-degree cube rotation is used to move point 100 to its subsequent location. → Select cube points 100 to 103 on the left camera video using the centroiding function starting with point 100 on the upper-left corner of the calibration cube through 5 orientations then after each cube rotation and orientation until point 100 returns to its initial position.

After step 1d, only the left camera video main points need to be selected as the right camera video main points and both left and right camera video front and back points will automatically populate. For the tilted forward and tilted back orientations, the main points should be taken when the tilt angle is greatest and the calibration cube is not in motion.

2. Point processing

a. After marking the left camera video main points in all 5 orientations for each of the 4 cube rotations there should be 20 pairs of image file records on the lower left "Image file" box. Check to see that there are no missing records and all records have a "Yes" in the "Oriented" column.

b. Adjustment → Adjustment settings → "Critical value for base rejection" should be 5000.0 µm (micrometers) → Close dialog

c. Adjustment → Compute bundle adjustment → Adjustment results box will appear and should say "Adjustment SUCCEEDED" → Double-click "Object point summary" → "Relative precision" should be 1:5000 or greater → Close dialog → Accept results

A "relative precision" below 1:5000 indicates a lack of cube points detected or a possible error in point placement; see Troubleshooting section for possible solutions.

d. Measurement → View/delete image measurements → Sort by "Rejected" by clicking on the column header → Select and delete all "rejected" points → Sort by "Residual magnitude" by clicking on the column header → Delete values over 1 → Close dialog

e. Measurement → Find targets in all images

f. Repeat step c and d.

g. Repeat step c.

"Relative precision" in the Adjustment results should increase from the initial value during the first bundle adjustment computation.

h. Measurement → Stereo constraints → Configure stereo constraints → Select "Automatic" for Pairings → OK

i. Measurement → Stereo constraints → Estimate constraints → Precision of "Base separation (X)" should be less than 1000 µm → Close dialog

j. Measurement → Stereo constraints → View stereo constraints → There should be less than 5 "Exclusions," the absolute value of "Base res." should be under 2000 µm, and the absolute value of all other categories should be under 300 s (seconds) → Close dialog

Stereo constraints that exceed categorical limits are not necessarily indicative of a bad calibration as long as relative precision is at least 1:5000 and precision of base pair separation (X) is under 1000 µm, but improvements should still be explored. Refer to the Troubleshooting section for possible solutions.

k. Measurement → Stereo constraints → View relative orientation → File → Save data to text file → Save → Close dialog

3. Troubleshooting

a. If an image file record has very few points (< 50) or is not oriented, select and delete the left and right pair of image records, move a few frames forward or back paying close attention to the clarity of cube points and if any pause in the video occurs, then re-select points 100 to 103 and repeat step 2. Adjusting the brightness and contrast may also yield better point clarity.

b. If the relative precision is less than 1:5000, find the image file records with the lowest point counts and repeat step 3a for those records.

c. If stereo constraints are above the categorical limits, go to the left or right image file pair indicated in the “Stereo constraints” box and look for possible point errors or missing points; repeat step 3a.

Each time a new image file record pair is produced, the entire calibration “Point processing” section has to be repeated before proceeding to calibration file generation. A relative precision remaining under 1:5000 after troubleshooting is indicative of a calibration failure and resulting calibration files should not be used for measurement. A calibration failure is typically due to issues with video quality and/or video recording.

4. Generating calibration files

a. Camera → Left → Edit parameters → Edit “Descriptor” field and write in MOUSS unit and date: MOUSS_unit letter_calibration date_left (e.g., MOUSS_01_20170101_left)

b. Camera → Right → Edit parameters → Edit “Descriptor” field and write in MOUSS unit and date: MOUSS_unit letter_calibration date_right (e.g., MOUSS_01_20170101_right)

c. Measurement → Stereo constraints →Export stereo camera files → Left Camera parameters box appears → Close dialog → Save it Now? Yes → Enter .Cam file filename as follows: MOUSS_unit letter_calibration date_left (e.g., MOUSS_01_20170101_left) → Save → Right Camera parameters box appears → Close dialog → Save it Now? Yes → Enter .Cam file filename as follows: MOUSS_unit letter_calibration date_right (e.g., MOUSS_01_20170101 _right) → Save

d. Close CAL → Object points → Save it Now? Yes → Save → Measurements → Save it Now? Yes → Save → Left camera → Save it Now? Yes → Save → Right camera → Save it Now? Yes → Save

Once a set of camera and cube calibration files is used in a calibration they cannot be re-used to calibrate other MOUSS units as their parameters will have been changed; this is why the original starter set of camera and cube calibration files is used for each calibration.

Calibration Accuracy Check

1. Get measurements using EventMeasure

a. Open EventMeasure software → Measurement → New measurement file

b. Measurement → Information fields → Edit field values → Enter calibration project file name (e.g., MOUSS_01_20170101) for “OpCode” and your initials in “Tape Reader” field → Close dialog

c. Picture → Set picture directory → Select folder with calibration files and videos → OK

d. Uncheck “Lock” box next to the left video frame step controls → Picture → Load picture → Select left camera calibration video file (slave) → Open

e. Picture → Define movie sequence → Add file(s) → Select left camera calibration video file (slave) → Open → OK

f. Stereo → Picture → Load picture → Select right camera calibration video file (master) → Open

g. Stereo → Picture → Define movie sequence → Add file(s) → Select right camera calibration video file (master) → Open → OK

h. Adjust videos to the sync difference determined during calibration, if necessary, using the frame step controls then check the "Lock" box next to the left video frame step controls

i. Stereo → Cameras → Left → Load camera file → Select left camera file (e.g., *MOUSS_01_20170101_left.Cam*) → Open

k. Stereo → Cameras → Right → Load camera file → Select right camera (e.g., *MOUSS_01_20170101_right.Cam*) file → Open

l. Play left video until calibration cube is in water, in view of both cameras, and all main front and back points are visible → Close player and update position → Using the centroiding function, take measurements as seen in the figures below (Figure A.2)

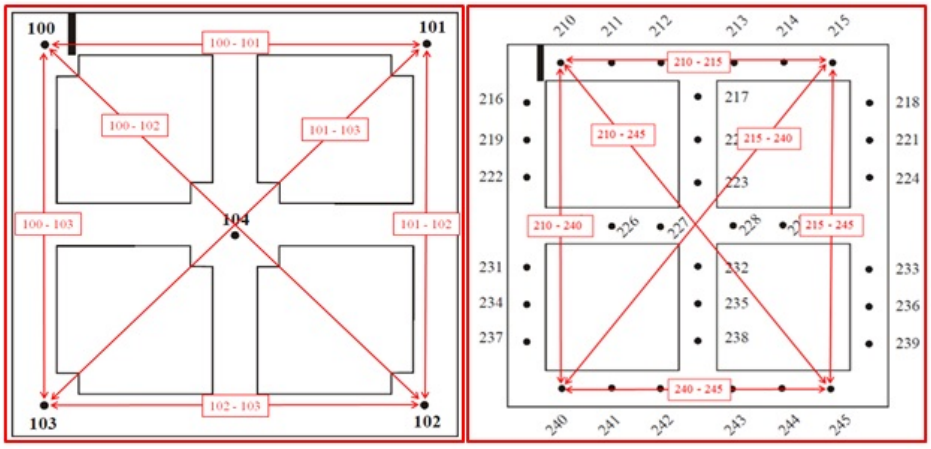

Figure A.2 Measurements taken between points on the front (left) and back (right) of the calibration cube.

If centroiding is not possible, points can be manually placed by zooming in and selecting the center of a cube point. To zoom, select the desired level of magnification, place the cursor over the area of the video screen to be magnified, hold down the Ctrl key, then move the cursor slightly. It is better, however, to move to a different video frame where centroiding may be accomplished to obtain the measurements, since manual point placement is usually less accurate than centroiding.

2. Compare measurements for accuracy

a. Compare measurements to the actual point distance below (Table A.1). The difference should be within 2 mm.

Table A.1 Actual point distances between points measured on the calibration cube.

To/from points	Distance (mm)
100 to 101	898.6820
100 to 102	1272.6655
100 to 103	900.8719
101 to 102	901.6515
101 to 103	1272.6973
102 to 103	898.4878
210 to 215	751.4910
210 to 240	1003.0086
210 to 245	1254.1523
215 to 240	1251.3889
215 to 245	1002.0929
240 to 245	750.9568

b. Measurement → Measurement summaries → Length measurements → File → Save data to text file → Enter calibration project file name (e.g., MOUSS_01_20170101) → Save → Close dialog

c. Measurement → Save → Enter calibration project file name (e.g., MOUSS_01_20170101) → Save → Close EventMeasure

d. Copy the calibration files (.Cam files) into "CAM files" folder (Calibration → CAM files) and record the calibration results (.Cam file name, precision, accuracy, comments) in "Calibration history" excel sheet (Calibration → CAM files → Calibration history.xls)

Appendix B: MOUSS Deployment and Recovery Protocol

The step-by-step MOUSS deployment and recovery protocol is as follows:

MOUSS Deployment

1. Upon locating the desired deployment site, move the boat to within an appropriate distance of the deployment site given conditions (example: calm—close to the site; rough –150 m up-current) and hold position while the MOUSS is prepared for deployment.

2. Connect the following to the MOUSS harness center ring: 1) two sub-surface floats, 2) suitable length of surface line with attached surface buoys and 3) the deployment line with quick-release clip. Feed the deployment line through the block and pinch puller, taking up any slack.

3. Connect the bottom line to the anchor weight with the clip and feed the weight-release line through the clip. Cleat off and hold the weight-release line, then manually lift and push the anchor weight overboard, hanging the weight from the weight release line. Retain the other end of the bottom line on the boat.

4. Remove the lens covers from the cameras and start the cameras recording by removing the dummy plugs and connecting the DVR bottle and battery bottle with the battery cord. Connect the “MOUSS Pi” unit to make sure the cameras are recording and perform a hand signal in front of the cameras as a “sync” action.

5. Manually lift the MOUSS onto the gunwale while taking up any slack in the line with the pinch puller.

6. While holding the MOUSS steady, attach the other end of the bottom line to the MOUSS harness on the clip underneath the MOUSS. Attach the loaded bait arm to the MOUSS, securing it with the bait clip.

7. Move the boat to the deployment site. Using the pinch puller, lift the MOUSS up off the gunwale and into the water, so that it is suspended from the davit at the water surface.

8. When the boat is over the deployment site, use the quick release clip to deploy the MOUSS. Mark the actual deployment site on the GPS and record the metadata on the data sheet.

9. Release the deployment line to release the anchor weight so the MOUSS will begin to sink. Ensure that the surface line feeds freely into the water as the MOUSS sinks while carefully moving the boat away from the deployment site. When all the surface line is out, send the surface buoys overboard to complete the MOUSS deployment.

MOUSS Recovery

1. After the minimum deployment time has elapsed, return to the deployment site and position the boat near the surface buoys. Grab the surface line with the boat hook.

2. Pull the surface buoys onboard and pull in enough line so that the slack line can be safely fed through the pinch puller. If there is a lot of slack line on the surface, hand-haul in the line. Stow the surface buoys along the side opposite the davit. Do not secure the buoys until after the MOUSS is onboard.

3. Use the pinch puller to retrieve the surface line, feeding the line directly into the line bin placed below the pinch puller. Surface line retrieval may take several minutes depending on the length of line deployed. Meanwhile, maintain the position of the boat to facilitate safe recovery of the line and MOUSS at a safe angle, depending on wave and current conditions and bottom topography.

4. When the MOUSS is spotted (sub-surface), prepare to stop the haul back and ready the boat hook with clip and MOUSS retrieval line. Lift the MOUSS as high as possible out of the water without pulling the MOUSS harness into the block. While steadying the MOUSS, use the boat hook to clip the line to the large ring on the bottom line. The other end of the MOUSS retrieval line is then cleated off.

5. Pull up the MOUSS retrieval line to transfer the anchor weight load to the boat itself, and unclip the bottom line from the MOUSS harness. Using the pinch puller, carefully reverse the surface line to lower the MOUSS onto the gunwale. Remove the bait arm and sub-surface floats and stow them along the bow.

6. Pull the MOUSS onboard into the boat. Once the MOUSS is fully onboard, disconnect the battery cord, stopping the cameras, and replace the dummy plugs. The surface line can also be safely disconnected at this time.

7. Connect the anchor weight retrieval line to the loop on the bottom line with a quick link. Feed the other end of the anchor weight retrieval line through the block and pinch puller.

8. Use the pinch puller to lift the anchor weight enough to slacken the bottom line so that the bottom line can be disconnected from the anchor weight. Then use the pinch puller to lift the anchor weight above the gunwale, pull the weight inward, and then reverse the pinch puller to lower the anchor weight safely onboard. Be careful to maintain control of the suspended load until the anchor weight is safely settled into position on deck.

Appendix C: Linux Commands for Data Download and Video Creation

Downloading MOUSS imagery

1. Syncing the master SSD to the primary external hard drive (HD)

a. Open the MOUSS DVR by first venting the port plug and removing the green lock string. Remove the master SSD and insert into a docking station along with the appropriate primary external HD (hereafter primary HD). Connect the MOUSS laptop to the docking station, turn on the docking station, and ensure that both drives are properly mounted.

b. Open a Linux terminal (Ctrl + Alt + T) and change directory into the target directory for the master drive:

```
cd /media/mouss/[DRIVE NAME]/data/[DVR NAME]/master
```

where [DRIVE NAME] is the name of the primary HD (e.g., se1701_001)
and [DVR NAME] is the name of the DVR unit that captured the images (e.g., dvr_01)

c. Run the rsync command to copy all of the files in the master SSD to the primary HD:

```
rsync -aP /media/mouss/IMAGES/images/* ./
```

d. For troubleshooting purpose, please copy the log file and configuration files. Open another Linux terminal and run the rsync command to copy the system log and configuration files for the master SSD for that specific day:

Create the master log directory for the master SSD:

```
mkdir /media/mouss/[DRIVE NAME]/data/[DVR NAME]/master/log_[CURRENT DATE]
```

Change the current directory to the master log directory:

```
cd /media/mouss/[DRIVE NAME]/data/[DVR NAME]/master/log_[CURRENT DATE]
```

Copy the config.json file to the master log directory:

```
rsync -aP /media/mouss/[OS PARTITION]/home/camera/config.json ./
```

Copy the syslog file to the master log directory:

```
rsync -aP /media/mouss/[OS PARTITION]/var/log/syslog ./
```

e. When the files are finished copying, safely remove the master SSD using “safely remove hardware” feature and then power down the docking station. Remove the master SSD from the docking station and remount back into the DVR.

2. Syncing the slave SSD to the primary external HD

a. Remove the slave drive and insert into the docking station with the primary HD. Turn on the docking station and ensure that both drives are properly mounted.
b. Open a Linux terminal (Ctrl + Alt + T) and change directory into the target directory for the slave drive:

    cd /media/mouss/[DRIVE NAME]/data/[DVR NAME]/slave

    where [DRIVE NAME] is the name of the primary HD (e.g., se1701_001)
    and [DVR NAME] is the name of the DVR unit that captured the images (e.g., dvr_01)

c. Run the rsync command to copy all of the files in the slave SSD to the primary HD:

    rsync -aP /media/mouss/IMAGES/images/* ./

d. While the images are copying, open another Linux terminal and run the rsync command to copy the system log and configuration files for the slave SSD for that specific day:

    Create the slave log directory for the slave SSD:

    mkdir /media/mouss/[DRIVE NAME]/data/[DVR NAME]/slave/log_[CURRENT DATE]

    Change the current directory to the slave log directory:

    cd /media/mouss/[DRIVE NAME]/data/[DVR NAME]/slave/log_[CURRENT DATE]

    Copy the config.json file to the slave log directory:

    rsync -aP /media/mouss/[OS PARTITION]/home/camera/config.json ./

    Copy the syslog file to the slave log directory:

    rsync -aP /media/mouss/[OS PARTITION]/var/log/syslog ./

e. When the files are finished copying, safely remove the slave SSD using “safely remove hardware” feature and then power down the docking station. Remove the slave SSD from the docking station and remount back into the DVR. Put the DVR back into the housing and lock it using the green string.

Creating MOUSS Videos

1. Convert images to videos on the primary HD for both the master and slave data

To create the videos, use a Perl script (Appendix D.1: Concurrent MOUSS Process Images) which searches the drive for SGI format images that have not been used to create a corresponding AVI videos, and when found launches another script (Appendix D.2: MOUSS Process Images) which automatically creates a video from those images. This script allows

simultaneous creation of multiple videos which is lot more efficient compare to manual creation. Ensure that all Perl scripts are located in ~/Documents/scripts/mouss before executing this step.

a. Turn on the docking station containing the primary HD.

b. Open a Linux terminal (Ctrl + Alt + T) and change directory into the DVR name folder that was just downloaded

```
cd /media/mouss/[DRIVE NAME]/data/[DVR NAME]
```

where [DRIVE NAME] is the name of the primary HD (e.g., se1701_001)
and [DVR NAME] is the name of the DVR unit that captured the images (e.g., dvr_01)

c. Run the Perl script to concurrently convert all videos in the master and slave folders:

```
perl ~/Documents/scripts/mouss/concurrent_mouss_process_images.pl
```

2. Retrieve all MOUSS drop statistics

The drop statistics include the number of images collected by the master and slave cameras for each deployment. This information is useful to determine that the cameras are working properly and not turning off during deployment, dropping frames, or experiencing other errors. This step uses a Perl script (Appendix D.3: MOUSS Image Count) to count the images and save the information as a CSV file. Ensure the Perl script is located in ~/Documents/scripts/mouss before executing this step of the SOP.

a. Plug in docking station(s) containing all of the primary HDs to the MOUSS computer and make sure each one is mounted properly.

b. Open a Linux terminal (Ctrl + Alt + T) and change directory into the /media/mouss directory:

```
cd /media/mouss
```

c. Run the Perl script to export the MOUSS image statistics to a CSV file (~/Documents/mouss_image_counts.csv):

```
perl ~/Documents/scripts/mouss/mouss_image_count.pl >
~/Documents/mouss_image_counts.csv
```

d. Take the output CSV file (e.g., mouss_image_counts.csv) file and open it in LibreOffice Calc or Excel. Copy and paste the CSV file contents into the corresponding Google Sheet in the "MOUSS Image Info Export" tab. This will update all the "# of pics" values in the "MOUSS Results" tab.

e. When finished, safely remove the primary HD using “safely remove hardware” feature and power down the docking station.

MOUSS Data Backup

Ensure that all files on the primary HD are properly archived on the backup HD.

a. Insert the backup HD into the docking station along with the appropriate primary HD.

b. Turn on the docking station and ensure both HDs are properly mounted.

c. Open a Linux terminal (Ctrl + Alt + T) and change directory into the backup HD where [BACKUP DRIVE NAME] is the name of the backup HD (e.g., se1701_002):

```
cd /media/mouss/[BACKUP DRIVE NAME]/data
```

d. Sync the primary and backup HDs

where [PRIMARY DRIVE NAME] is the name of the primary HD (e.g., se1701_001):

```
rsync -aP /media/mouss/[PRIMARY DRIVE NAME]/data/* ./
```

e. When finished, safely remove both drives using “safely remove hardware” feature and power down the docking station.

Configuring MOUSS DVRs

The large size and frequency of the images recorded typically causes the hard drives to fill up in 3-4 days depending on survey tempo, so the data must be erased periodically to ensure there is always enough space to collect new images. However, longer deployment times may cause them to fill up more quickly, so it is important to check the space available on the DVR daily. Additionally, the system time (in UTC) on the DVRs should be checked and re-set every 2-3 days to ensure accuracy of the timestamps for the recorded images.

This procedure should only be done at the end of the day after all of the images have been downloaded, the videos successfully processed, and the data copied to the backup hard drives.

1. Ensure there is enough available space on the master SSD for the next day

a. Connect the MOUSS DVR unit to a power supply; connect the LAN adapter to the middle outlet in the DVR unit; and plug the network cable into the MOUSS laptop. Check that the IP address is set to “mouss”.

b. Open a Linux terminal (Ctrl + Alt + T) and use ssh to connect to the master computer in the DVR (IP address is 192.168.0.10) that control the master camera:

```
ssh camera@192.168.0.10
```

Enter the camera password (camera)

Stop the camera service:

```
sudo killall -INT camera_svc
```

c. Check the HD space on the master SSD:

```
df -h
```

d. Examine the data partition (/data) for available disk space. There should be at least 150 GB of disk space available in the data drive at the beginning of operations each day to safely capture all new images on a given day. If the DVR unit is on for longer than normal, more disk space is necessary to capture all of those additional images.

e. To erase data in the data partition, execute the script below:

```
sudo ./erase_image_partition
```

Enter the camera password (camera)

If sudo has been entered recently, the computer won't ask you for the camera password again.

f. To verify the data partition is empty:

```
df -h
```

2. Sync the field computer time with the master camera computer

a. Set the field computer clock UTC. Under the field computer's Settings option, toggle the time between automatic and manual to update. Make sure field computer is connected to the internet.

b. Connect to the MOUSS network and determine the IP address for the field computer.

c. Open a Linux terminal (Ctrl + Alt + T) and use ssh to connect to the DVR's master computer. If this is done immediately following Step 1, it will already be connected.

d. Sync master computer time with the field computer's time:

```
sudo date --set="$(ssh mouss@192.168.0.200 'date -u')"
```

Enter the camera password when prompted (camera)

Enter the mouss password when prompted (mouss)

e. Enter the sudo command one more time immediately afterwards, and enter the mouss password immediately when prompted. The command uses the field computer time when the command is executed, and it is only applied once the command is authenticated. As such, there will be some discrepancy between the two computers times, but if it is within a second then it is acceptable.

f. Compare the DVR master computer time against the field computer's time. Open another terminal window (Ctrl + Alt + T) and type "xclock -digital -update 1". This will display the field computer date and time real time updating every second.

g. Type "date" into the MOUSS terminal window to check the discrepancy between the two times. Do this at 10 seconds or so intervals, so that it is easier to check. Both time are in UTC but the field computer may display it in AM/PM mode while the MOUSS computer displays it in 24 hour mode.

h. Shut down the master computer:

```
sudo shutdown -h now
```

i. Give the system approximately 20 seconds to stop before disconnecting the power from the DVR.

3. Repeat steps 1 and 2 for the slave computer

Disconnect the power supply from the DVR unit for approximately 30 seconds, and then power up the unit again. Repeat the exact same process (Configuring MOUSS DVR 1-2) for the slave computer using the slave IP address (192.168.0.11).

4. Double check the SSD free space and time for both the master and slave in the DVR

If everything looks good, then power down the DVR and mark it as ready for operations.

Appendix D: Perl Scripts

1. Concurrent MOUSS Process Images

```
#!/usr/bin/perl

############################
#
# created: 20171024, jda
#
# from DVR folder (e.g., /media/mouss/se1701_001/data/blue_01)
# input: concurrent_mouss_process_images.pl date value in YYYYMMDD format (e.g., perl
~/Documents/scripts/concurrent_mouss_process_imagesv2static.pl 20170101)
#
# this script requires and calls helper_mouss_process_images.pl
#
############################


use threads;
use Cwd;

#counter for the number of threads used:
my $thread_counter = 0;

#the directory the program was launched from
my $home_dir = getcwd();

#print "date => @ARGV[0] \n";

#find all mouss drop folders
@data = `find . -type d | grep '[0-9]\\{8\\}_[0-9]\\{6\\}\$'`;
#@data = `find . -name *@ARGV[0]* -type d`;

#print @data;
#exit;

#create a new array for the threads that will be created:
@threads = ();

#loop through each of the slave and master folders returned by the find command:
foreach(@data){
# for each of the folders in master and slave that match the current date value execute the
helper_mouss_process_images.pl script on that directory in a separate thread

#format @data to full path
        chomp();
```

```
	s/\.//g;

#changed to drop directory

#print "=> $_\n";
	@files = <$home_dir$_/*.avi>;
#	@files = <*.avi>;
	if(! @files){
		chdir("$home_dir$_") or die "cannot change: $!\n";
		$current = getcwd();
		print "current: $current\n";

		#create the new helper_mouss_process_images.pl thread and add it to the msc
subroutine:
		$threads[$thread_counter] = threads->create('msc', 'perl
/home/mouss/Documents/scripts/mouss/mouss_process_images.pl ');
		#$threads[$thread_counter] = threads->create('msc', 'perl
~/Documents/scripts/helper_mouss_process_images.pl '.$_);

		print "the current thread expression is: perl
/home/mouss/Documents/scripts/mouss/mouss_process_images.pl\n";
#		print "the current thread expression is: perl
~/Documents/scripts/helper_mouss_process_images.pl\n";

		#increment the thread counter
		$thread_counter ++;
	}else{
		print "found Avi\n";
	}
#sleep(1);
}

#loop through each thread element and join (execute) them:
foreach (@threads)
{
	print "join: $_";
	#join the current thread
	$_->join();
}

#subroutine for executing multiple threads
sub msc
{
system ( @_ );
}
```

2. MOUSS Process Images

```
#!/usr/bin/perl

##########################
#
# created: 20160722, jct
#
# from the dive directory
# input: perl mouss_process_images.pl
#
#
##########################


use Cwd;
use File::Copy qw(move);


my $FR = 12;
my %frame_rate = ("10" => .1, "12" => .0833, "14" => .0714, "2" => .5, "5" => .2);
my $bin = 2;
my $master_dir = getcwd;
my @path = split /\//, $master_dir;
my $master_dive = $path[-1];
my $dvr = $path[-3];
my $image_type = "sgi";
my @master_image_list = <*.sgi>;
#print "Original number of images: $#master_image_list\n";
my $camera = $path[-2];
my $number_of_sample_images = 50;


#working section

        &write2log("Started processing:");
        &if0mv(@master_image_list);
        @master_image_list = <*.sgi>;
#print scalar "Fixed number of images: $#master_image_list\n";
        &sample_images($number_of_sample_images,@master_image_list);

#exit;
        &find_image_index_gaps(@master_image_list);
        &create_video($dvr,$master_dive,$FR,$camera);
        &write2log("Finished processing:");
```

```
sub find_slave_dir{
	my @return_date = (20000101,999999);
	my @return_time = (999999,999999);

print "$_[0]\n";
	my $dirname = $_[0];
	print "input2 => $_[1]\n";
	my @master_dive_info = split /_/, $_[1];
	my $master_dive_date =
$master_dive_info[0],$master_dive_info[1],$master_dive_info[2];
	my $master_dive_time = $master_dive_info[1];
	print "$master_dive_date, $master_dive_time\n";

	opendir my($dh), $dirname or die "Couldn't open dir '$dirname': $!";
	my @files = readdir $dh;
	closedir $dh;
	foreach(@files){
		my @slave_dive_info = split /_/, $_;
		my $slave_dive_date = $slave_dive_info[0];
		my $slave_dive_time = $slave_dive_info[1];
		if (/^\d/){
			$date_diff = abs($slave_dive_date - $master_dive_date);
			$time_diff = abs($slave_dive_time - $master_dive_time);
			print "$_ => date diff: $date_diff, time diff: $time_diff\n";
			@return_date = &less(@return_date,$slave_dive_date,$date_diff);
			@return_time = &less(@return_date,$slave_dive_date,$date_diff);
		}
	}
	print "\n";

}

sub less{
	print "input: $_[1] < $_[3] => @_\n";
	if ($_[1] < $_[3]){
		print "return: $_[0], $_[1]\n";
		($_[0],$_[1]);
	}else{
		print "return: $_[2], $_[3]\n";
		($_[2],$_[3]);
	}

}

#input: array of image files
```

```
sub find_image_index_gaps{
	print "$_[0]\n";
	my @image_info = split /\./, $_[0];
	my $first_image = 1;

	my $temp_counter = 0;
	my $gap_number = 0;

	foreach(@_){
		my $last_index_number = $image_info[3];
		$temp_counter++;
		if($first_image == 1){
			$first_image = 0;
			next;
		}

		my @current_image_info = split /\./, $_;
#		print "last: $last_index_number => $_, $current_image_info[3] ";
		my $index_diff = $current_image_info[3] - $last_index_number;
		if($index_diff > 1){
			$gap_number++;
			print "gap detected $index_diff => @image_info ==
@current_image_info\n";
print "time estimate: " . &time_estimate($image_info[3],$FR) ."\n";;
			&write2log("Gap deteched: " . ($index_diff-1) ." images missing between
$image_info[0].$image_info[1].$image_info[2].$image_info[3].$image_info[4] and
$current_image_info[0].$current_image_info[1].$current_image_info[2].$current_image_info[3]
.$current_image_info[4] (time estimate: " . &time_estimate($image_info[3],$FR) .")");
			&create_blank_image($index_diff-
1,$last_index_number,"$image_info[0].$image_info[1].$image_info[2].",".sgi");
		}
#		print "\n";
		if($temp_counter>10){
#			last;
		}
		@image_info = @current_image_info;
	}
	print "Gaps dectected: $gap_number\n";

}


sub find_image_time_gaps{

}
```

```
#input: number of images to create, index number, before the index number, after the index
number

sub create_blank_image{
	my $counter = 1;
	my $org_image = "$_[2]$_[1]$_[3]";
	`mogrify -format jpg $org_image`;
	my @org_image_info = split /[x:]/, `exiftool -ImageSize $_[2]$_[1].jpg`;
	unlink "$_[2]$_[1].jpg";
#	print "$org_image_info[1] $org_image_info[2]\n";
	$org_image_info[1] =~ s/ //;
	$org_image_info[2] =~s/ //;
	chomp($org_image_info[2]);
	while($_[0]>=$counter){
		my $new_image_name = sprintf "$_[2]%.6d.blank$_[3]", ($counter+$_[1]);
#		my $new_image_name = sprintf "$_[2]%.6d.blank.jpg", ($counter+$_[1]);
		print "$new_image_name\n";
		&write2log("Creating image: $new_image_name");
		`convert -size $org_image_info[1]x$org_image_info[2] xc:black
$new_image_name`;
		$counter++;
	}
}

sub write2log{
	my $success = open LOG, ">>processing_log.txt";
	if (! $success){
		die "Cannot create processing log file: $!\n";
	}
	print LOG localtime() . " => @_\n";
	close LOG;
}

#input: dvr, dive name, frame rate, master/slave
sub create_video{

	&write2log("Creating video: $_[0].$_[1].fr$_[2].$_[3].avi");
	`mencoder mf://*sgi -mf fps=$_[2]:type=sgi -ovc xvid -xvidencopts bitrate=16000 -o
$_[0].$_[1].fr$_[2].$_[3].avi`;
	&write2log("finished creating video: $_[0].$_[1].fr$_[2].$_[3].avi");
}

#input: frame number, frame rate
sub time_estimate{
#	print "input: @_\n";
	my $min = int($_[0] * $frame_rate{"$_[1]"}/60);
```

```
	my $sec = int(($_[0] * $frame_rate{"$_[1]"})-($min*60));

#	print "Min: $min\nSec: $sec \n";
	"$min:$sec";

}

#input: list of images
sub if0mv{
	my $empty_images_dir = "empty_images";
	my $empty_image_count = 0;
#print "dir name: $empty_images_dir\n";
	&create_dir("$empty_images_dir");
#	&create_dir("empty_images");
	foreach(@_){
#	print "=>$_\n";
#		last;
		if (-z "./$_"){
#			print "$_ is empty.\n";
			move $_, "./$empty_images_dir/$_";
			&write2log("Moved image $_ to $empty_images_dir directory.");
			$empty_image_count++;
		}
	}
	if ($empty_image_count > 0){
		&write2log("Empty images found: $empty_image_count");
	}
}

#input: name of directory
sub create_dir{
#print "==>$_[0]\n";
	my $directory = $_[0];
	if(!-d $directory){
#		print "creating $directory\n";
		unless(mkdir $directory) {
			die "Unable to create $directory\n";
		}
		&write2log("Created directory: $directory");
	}
}

#input: number to sample, list of images
sub sample_images{
	my $sample_image_dir = "sample_images";
	my $num_images_needed = shift @_;
```

```
	my $grab_every = int($#_/$num_images_needed);
#	print "grab every: $grab_every\n";

	&create_dir("$sample_image_dir");

	my $count = 0;

	foreach(@_){
		$count++;
		if($count >= $grab_every){
			$count = 0;
#			print "$_\n";
			my $new_image_name = &convert_image($_,"jpg");
			move $new_image_name, "./$sample_image_dir/$new_image_name";
			&write2log("Moved image $new_image_name to $sample_image_dir
directory.");
		}

	}

}

#input: image name, new image format (jpg,....)
sub convert_image{
	`mogrify -format $_[1] $_[0]`;
	$_[0] =~ s/sgi/$_[1]/;
	&write2log("Created image: $_[0]");
	$_[0];
}
```

3. MOUSS Image Count

```
#!/usr/bin/perl

############################
#
# created: 20171023, jct
#
# from data dir
# input: perl mouss_image_count.pl
# this should be run from the /media/mouss folder for a given drive name and will produce a file
in the same directory name mouss_image_counts.csv
#
#
############################
```

```
use Time::Local;
use POSIX qw(strftime);

#   this one works from the DVR name folder
#   open DATA, "find . -name '[0-9]*_[0-9]*' -type d  |"   or die "Couldn't execute program: $!";


#print out the csv header:
print "DVR Name,Master Drop Name,Master Drop ID,Master Photo Count,Slave Drop
Name,Slave Drop ID, Slave Photo Count\n";


#from the root /media/mouss directory find all of the mouss_se####_### directories:
#execute the find command to retrieve all of the drop folders:
open DRIVE_NAMES, "find . -name 'mouss_se[0-9]*_[0-9]*' -type d | sort  |"   or die "Couldn't
execute program: $!";

#loop through the output from the linux command to process each directory:
while ( defined( my $line = <DRIVE_NAMES> )  ) {

        chomp ($line);

#       print "the current drive directory name is: ".$line."\n";

        #check if the current directory matches the mouss_se####_### drive name convention:
        if ($line =~ m/\.\/mouss_se[0-9]{4}_[0-9]{3}/)
        {
                #the current directory name is the ./mouss_se_####_### folder:
#               print "the current directory name is the ".$line."\n";


                #from the mouss_se####_###/data directory loop through each of the dvr drop
folders:

                #array to hold the different pieces of information
                #[$x][0] dvr name
                #[$x][1] master drop name (dvr name." ".master drop name)
                #[$x][2] master drop ID
                #[$x][3] master unix timestamp
                #[$x][4] # master pics
                #[$x][5] slave drop name (dvr name." ".slave drop name)
                #[$x][6] slave drop ID
                #[$x][7] # slave pics
                @data_array = ();
```

```
		#variable to store the total number of directory entries returned by the find
command:
		my $num_directory_entries = 0;


		#execute the find command to retrieve all of the drop folders:
		open DATA, "find ".$line."/data -name '[0-9]*_[0-9]*' -type d | sort  |"   or die
"Couldn't execute program: $!";

		#loop through the output from the linux command to process each directory:
		while ( defined( my $line = <DATA> )  ) {


			#check that this is a non-calibration folder that matches the following
pattern:
			#./mouss_[a-z]{2}[0-9]{4}_[0-9]{3}/data/[a-zA-Z]_[0-
9]{3}/(master|slave)/[0-9]{8}_[0-9]{6}

			chomp($line);
#			print "The current line is: ".$line."\n";
			if ($line =~ m/^\.\/mouss_[a-z]{2}[0-9]{4}_[0-9]{3}\/data\/[a-zA-Z]*_[0-
9]{2,3}\/(master|slave)\/[0-9]{8}_[0-9]{6}$/)
			{

				#this is a valid master/slave drop folder:

#				print "The current line is a valid master/slave drop folder:
".$line."\n";


				#parse the path value by the forward slash character:
				@path_array = split /\//, $line;


				#extract the date values to create a timestamp:
				$year = substr($path_array[5], 0, 4);
				$month = substr($path_array[5], 4, 2);
				$day = substr($path_array[5], 6, 2);
				$hours = substr($path_array[5], 9, 2);
				$minutes = substr($path_array[5], 11, 2);
				$seconds = substr($path_array[5], 13, 2);
				#create a timestamp for the given drop date/time value
				$time = timelocal($seconds, $minutes, $hours, $day, ($month - 1),
$year);
```

```
#                       print "Scalar localtime gives: ", scalar(localtime($time)), "\n";

#                       print $time,"\n",scalar localtime $time;

                        #retrieve the .sgi file count for the given directory:
                        $count = `ls -1 $line | grep sgi | wc -l`;
                        chomp ($count);

                        #parse the dvr number:
                        @dvr_info = split /_/, $path_array[3];

                        #check if this is the slave or master drive, master values should
always come first:
                        if ($path_array[4] eq 'master')
                        {

#                               print "The current line is a master DVR\n";

                                #this is the master drive

                                #store each master value in a new array element:
                                $data_array[$num_directory_entries][0] =
int($dvr_info[1]);
                                $data_array[$num_directory_entries][1] =
int($dvr_info[1])."_".$path_array[5];
                                $data_array[$num_directory_entries][2] = $path_array[5];
                                $data_array[$num_directory_entries][3] = $time;
                                $data_array[$num_directory_entries][4] = $count;

                                #increment the number of directory entries:
                                $num_directory_entries ++;
                        }
                        else
                        {
                                #this is the slave drive
#                               print "The current line is a slave DVR\n";

                                #loop through each of the master drive entries to find a
match on the DVR name and the drop name (within +/- 5 seconds)
                                for ($i = 0; $i < $num_directory_entries; $i ++)
                                {
                                        #check if the dvr name matches a master entry and
that the timestamp is (within +/- 5 seconds)
                                        if ($data_array[$i][0] eq int($dvr_info[1]))
                                        {
```

```
                                                        #the dvr name matches the master entry,
check that the timestamp is within +/- 5 seconds
                                                        if (abs($data_array[$i][3] - $time) <= 5)
                                                        {
                                                                # a matching master was found for
the current slave:
                                                                $data_array[$i][5] =
int($dvr_info[1])."_".$path__array[5];
                                                                $data_array[$i][6] = $path_array[5];
                                                                $data_array[$i][7] = $count;

                                                                #the match was found, end the
current loop:
                                                                last;
                                                        }
                                                }
                                        }

                                        if ($i == $num_directory_entries)
                                        {
                                #                               print "The slave drive match was not found!!\n";
                                        }

                                }
                        }
                        else
                        {
#                               print "this is not a valid master/slave drop folder\n";


                        }

                }
                close DATA;

                #loop through the $num_directory_entries and print out each value:

                for ($i = 0; $i < $num_directory_entries; $i ++)
                {
                        #print out the current directory entry as a csv file:
                        print
$data_array[$i][0].",".$data_array[$i][1].",".$data_array[$i][2].",".$data_array[$i][4].",".$data_a
rray[$i][5].",".$data_array[$i][6].",".$data_array[$i][7]."\n";
                }
        }
}
```

Appendix E: MOUSS Video Annotation

The complete step-by-step protocol for MOUSS video annotation using SeaGIS EventMeasure™ software (version 5.25) is as follows:

The files needed to begin each new video annotation include:

- Camera calibration files: *MOUSS_01_20170101_left.Cam*

  MOUSS_01_20170101_right.Cam

  Camera calibration files are needed for each MOUSS unit with videos to be annotated (see Chapter 3 MOUSS Calibration). These paired left and right files are used to determine fish length.

- Attribute file: *SpeciesID.txt*

  This is a list of fish species found in the Main Hawaiian Islands. It should be changed to reflect appropriate species for a particular survey region.

- Reference image folder: *EventMeasure_PhotoGallery*

  This is a folder containing species photographs that analysts can reference during annotation.

These are example video files for the MOUSS cameras being annotated:

- Video files (slave/left): *M20170101_180513_MHI_s_12.avi* (master/right): *M20170101_180514_MHI_m_12.avi*

Setup

1. File organization requirements

a. Within the Annotation folder, create a working folder with a UTC date_time format (e.g., 20170101_180514) for the video pair being annotated based on the unique date and time stamp of the master video filename (e.g., *M20170101_180514_MHI_m_12.avi*). This unique date and time is the video ID, also referred to as the video "Op Code". The time for the master video is always used; never the slave.

b. Copy the master and slave videos and appropriate paired left and right calibration files (e.g., *MOUSS_01_20170101_left.Cam, MOUSS_01_20170101_right.Cam*) into the working folder. Refer to the survey metadata Google sheet to determine the correct calibration files to use.

2. Open EventMeasure software and setup a new measurement file

a. Measurement → New measurement file

3. Configure the reference image folder

a. Program →View reference images → Configure → Set "Picture Directory" to *EventMeasure_PhotoGallery* → Close dialog

4. Configure EventMeasure attributes

a. Measurement → Attributes → Edit/load species files → Set "Species file" to *SpeciesID.txt* → Close dialog

5. Configure EventMeasure data files (.EMObs files)

a. Measurement → Information fields → Edit field names → Enter "dvr_id" as the name for "Field heading 5", "drop_date" for "Field heading 6", "frame_rate" for "Field heading 7", "gear_id" for "Field heading 8", "mission_id" for "Field heading 9", "tdr_id" for "Field heading 10", "gps_id" for "Field heading 11", and "grid_id" for "Field heading 12" (Figure E.1) → Close dialog

Steps 3, 4, and 5a. only need to be done once for EventMeasure to retain these settings, however all configurations should be checked prior to the start of each new video annotation.

Figure E.1 Information field headings with appropriate names edited for fields 5 through 12.

b. Measurement → Information fields → Edit field values → Set "OpCode" code to the unique video ID (e.g., 20170101_180514; Figure E.2); enter the initials of the video analyst in the "Tape Reader" field (e.g., Rachel Louise Carson is entered as RLC); locate the information for the remaining fields in the Survey Metadata Sheet: "Depth" (in meters; e.g., 175), "Comment" (survey vessel initals; e.g., SE), "dvr_id" (e.g., 01), "drop_date" (e.g., 20170101), "frame_rate" (e.g., 12), "gear_id" (e.g., MOUSS_01), "mission_id" (e.g., SE1701), "tdr_id" (e.g., 1000), "gps_id" (e.g., A), and "grid_id" (e.g., 1010) → Close dialog

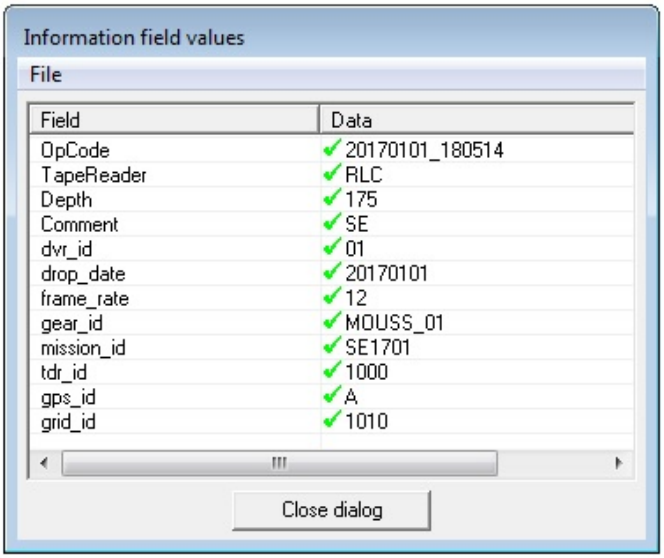

Figure E.2 Information field values with appropriate data entered for all fields.

c. Measurement → Save → Locate working folder for the videos being annotated and enter the video ID (e.g., 20170101_180514) as the file name → Save

The working folder name, EventMeasure file name (.EMObs file), and Op Code are all the same unique video ID (e.g., 20170101_180514).

6. Configure video files

a. Uncheck the "Lock" box next to the left camera frame step controls (Figure E.3).

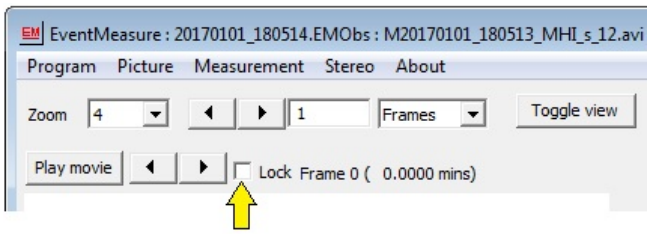

Figure E.3 Uncheck the lock box next to the frame step controls

b. Picture → Set picture directory → Browse for folder and select the appropriate working folder for the videos being annotated → OK

c. Picture → Load picture → Select the left/slave camera video file (e.g., *M20170101_180513_MHI_s_12.avi*) → Open

d. The Movie sequence configuration window will automatically list the left/slave video file (e.g., *M20170101_180513_MHI_s_12.avi*) → OK

e. Stereo → Picture → Load picture → Select the right/master camera video file (e.g., *M20170101_180514_MHI_m_12.avi*) → Open

f. The Movie sequence configuration window will automatically list the right/master video file (e.g., *M20170101_180514_MHI_m_12.avi*) → OK

g. Check the "Lock" box next to the left camera frame step controls.

7. Load camera calibration files (.Cam files)

a. Stereo → Cameras → Left → Load camera file → Select the left calibration file (e.g., *MOUSS_01_20170101_left.Cam*) → Open

b. Stereo → Cameras → Right → Load camera file → Select the right calibration file (e.g., *MOUSS_01_20170101_right.Cam*) → Open

8. Set length measurement rules

a. Stereo → Length/3D rules → Use length rules = "True", Apply RMS rule = "True", Maximum RMS = "10.0000" mm, Apply precision to length ratio rule = "True", Maximum precision to length ratio = "5.0000" %, Apply precision rule = "True", Maximum precision = "10.0000" mm (Figure E.4).

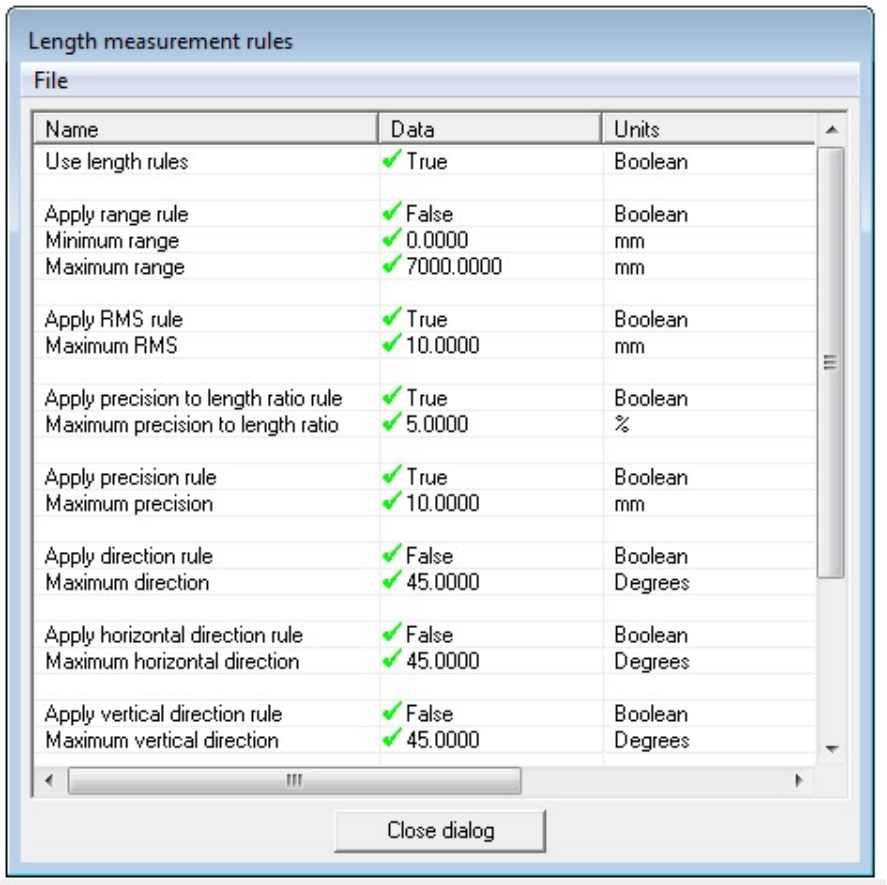

Figure E.4 Length measurement rules with appropriate data settings.

b. All other rules should be set to “False” → Close dialog

Step 8 only needs to be done once for EventMeasure to retain these settings; however, all configurations should be checked prior to taking measurements.

9. Synchronize left and right videos

a. Play left video until the first light sync sequence after camera touchdown is seen.

b. If needed, adjust brightness and contrast to improve image quality (Picture → Brightness and contrast; Toggle the Brightness and Contrast controls to adjust).

c. Uncheck the “Lock” box next to the left camera frame step controls.

d. Adjust the left or right camera video using the frame step controller so that the light sync sequences match. Note the frame difference, if any (L=R $\pm$ X).

e. Check the “Lock” box next to the left camera frame step controls.

10. Add synchronization markers

a. Right-click on the left camera light sync → Add point → Select “SYNC VALUE” from the “Family” drop down menu → Enter frame difference in the “Comment” field (L=R $\pm$ X) → OK

b. Take a measurement of the light sync (Figure E.5) by left-clicking on the horizontal end points on both the left and right video screens. Start with left point in left video then the corresponding point in the right video, and so on. Select “SYNC” from the “Family” drop down menu → Enter frame difference in the “Comment” field (L=R $\pm$ X) → OK

Figure E.5 Measurement of the light sync at the frame where the first light sequence is seen.

The sync measurement functions as a useful reference point. If the left and right videos fall out of sync at some point during video annotation, double-click on the "SYNC" measurement line in the "3D Measurements" data table to re-synchronize the videos at the frame where the sync measurement was taken.

11. Set period definitions

a. Play the left video and determine the time at which the camera first touches down on the seafloor; select "Close player and update position".

b. Right-click on the left video screen → Add point → Select "TOUCHDOWN" from the "Family" drop down menu → OK

c. Right-click on the left video screen → Period definitions → Add new period start → Enter new period name = "analysis" → OK

d. Play the left video until Period: analysis is 15:00:00; select "Close player and update position"; right-click on the left video screen → Period definitions → Set period end → Select "analysis" from Select period drop down menu → OK

Step 11 sets the video annotation period to 15 minutes; if you prefer a longer or shorter annotation period, adjust the time accordingly.

12. Save the EventMeasure file setup

a. Measurement → Save → Select the .EmObs file (e.g., *20170101_180514.EmObs*) → Save

Analysis Protocol

1. Species data collection

a. Each unique target fish species observed is marked with a point for "time of first arrival" (TOFA), and a point for the maximum observed count in a single frame of view (MaxN). This annotation protocol is specific to the 7 species of Hawaiian bottomfish collectively known as the "Deep 7" (Figure E.6): ōpakapaka (*Pristipomoides filamentosus*), kalekale (*P. sieboldii*), gindai (*P. zonatus*), ehu (*Etelis carbunculus*), onaga (*E. coruscans*), lehi (*Aphareus rutilans)*, and hapuʻupuʻu (*Hyporthodus quernus*). Non-target fish species that are encountered during annotation are marked with a point to indicate presence, but counts and lengths are not recorded for these fish.

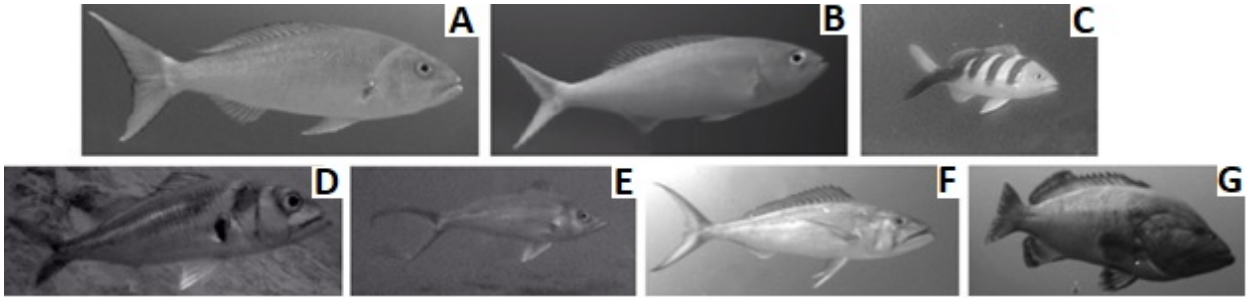

Figure E.6 The Deep 7 bottomfish as recorded by the MOUSS camera: (A) *Pristipomoides filamentosus*, (B) *P. sieboldii*, (C) *P. zonatus*, (D) *Etelis carbunculus*, (E) *E. coruscans*, (F) *Aphareus rutilans*, and (G) *Hyporthodus quernus*.

b. Each unique individual of a target species is measured 3 times (with each replicate measurement taken on a different frame) using the MaxN frame as a point of reference. Only individuals observed at the MaxN frame are measured, but measurements can be taken either before or after the time of MaxN, as long as the individual fish can be tracked back to the MaxN frame. At least two replicate measurements must be taken for each individual fish. If an individual cannot be measured (e.g., a fish is only appears partially on screen, or a fish is too far away from the camera for accurate measurement), or has less than two replicate measurements, a 3-D point is placed on that individual at the MaxN frame instead.

c. Only the left camera video is used to generate data points (e.g., TOFA, MaxN, non-target presence). The right camera video is used only when stereo-video measurements are taken.

d. Poor video quality due to factors such as water turbidity or lack of ambient light may lead to difficulties in fish identification. In such cases, video analysts should assign a fish ID to the lowest possible taxonomic level of certainty.

2. Fish observation and point marking

a. Play the left video starting at the point of camera touchdown by double-clicking the "TOUCHDOWN" data point to move the video to that frame; Once a target fish species is observed, select "Close player and update position" ("Close player" returns to the frame where the video began playing).

Video playback speed may be adjusted using the “Rate” arrows for slower (down) or faster (up) speed, as needed.

b. When a target fish first comes into the frame (Figure E.7), right-click on the fish → Add point →Select appropriate fish ID name starting with “Species”, “Genus”, or “Family” drop down menu selection → Type “TOFA” in the “Comment” field → OK

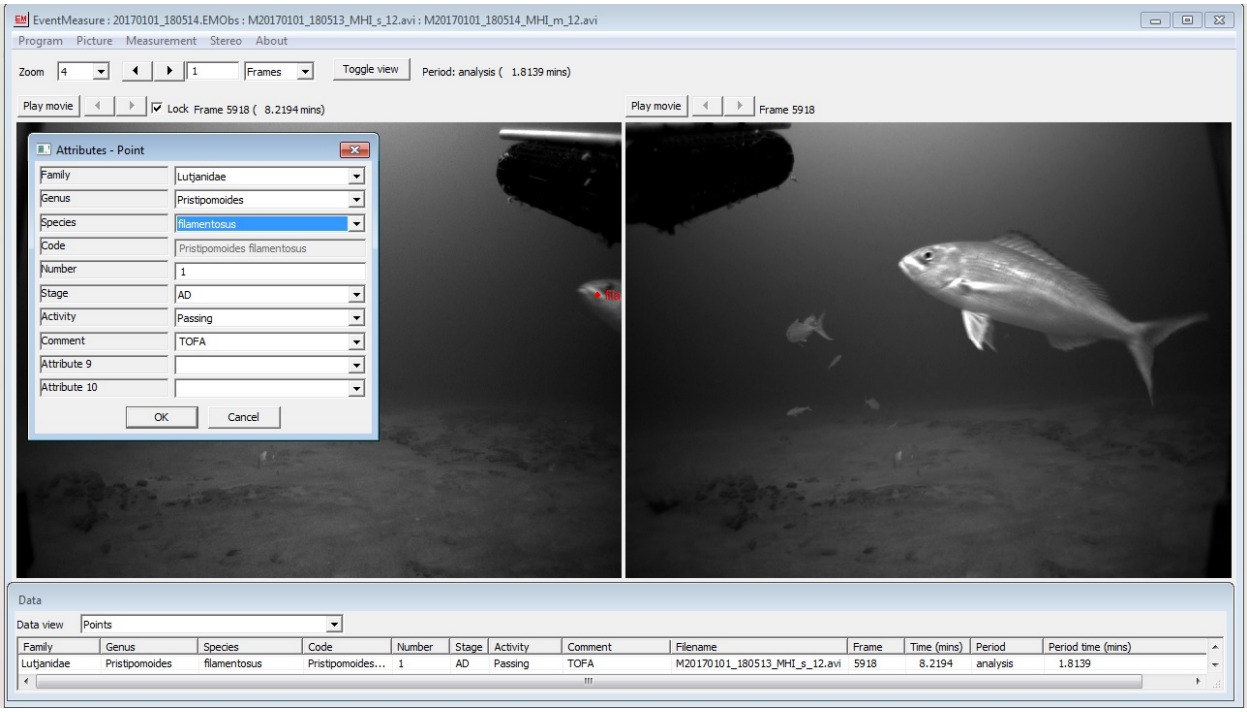

Figure E.7 "TOFA" point for first observation of Pristipomoides filamentosus.

Selecting a “Species” name in the drop down menu will automatically populate the “Genus” and “Family” fields, while selecting a “Genus” name will automatically populate the “Family” field. The possible choices available are listed on the Attribute file (*SpeciesID.txt*), and should be updated any time a new species is identified for a particular survey region.

c. If needed, use the reference image library to confirm fish IDs; select Program → View reference images → Select “Species”, “Genus”, or “Family” from the drop down menu selection → Reference images and/or videos will be displayed for each selection (Figure E.8).

Figure E.8 Reference images for *Pristipomoides filamentosus*.

d. When MaxN (i.e. the maximum fish count observed in a single frame) is found for a target species, right-click on the fish → Add point → Select the appropriate fish ID name with the lowest level of taxonomic certainty, either "Species", "Genus", or "Family" from the drop down menu selection → Enter the maximum fish count in the "Number" field → Enter "MaxN" in the "Comment" field → OK

The MaxN for a given target species will typically increase as the video progresses. It may be helpful to use a temporary point to mark each frame when a new, higher MaxN is found and then finalize the MaxN frame at the end of the 15-minute analysis period by deleting the lower counts. Video analysts are free to use other possible strategies and references for efficient video annotation, as long as the final data is accurate and consistent between analysts. Exact counts must be determined for fish schools with 20 individuals or less; for schools with more than 20 individuals counts may be estimated in increments of 5 or 10 depending on the total size of the school.

e. When a non-target fish species is observed (Figure 6.9), right-click on the fish →Add point →Select the appropriate fish ID name with the lowest level of taxonomic certainty, either "Species", "Genus", or "Family" from the drop down menu selection → Type "non-target" in the "Comment" field → OK (This is the only data point taken for non-target fish species.)

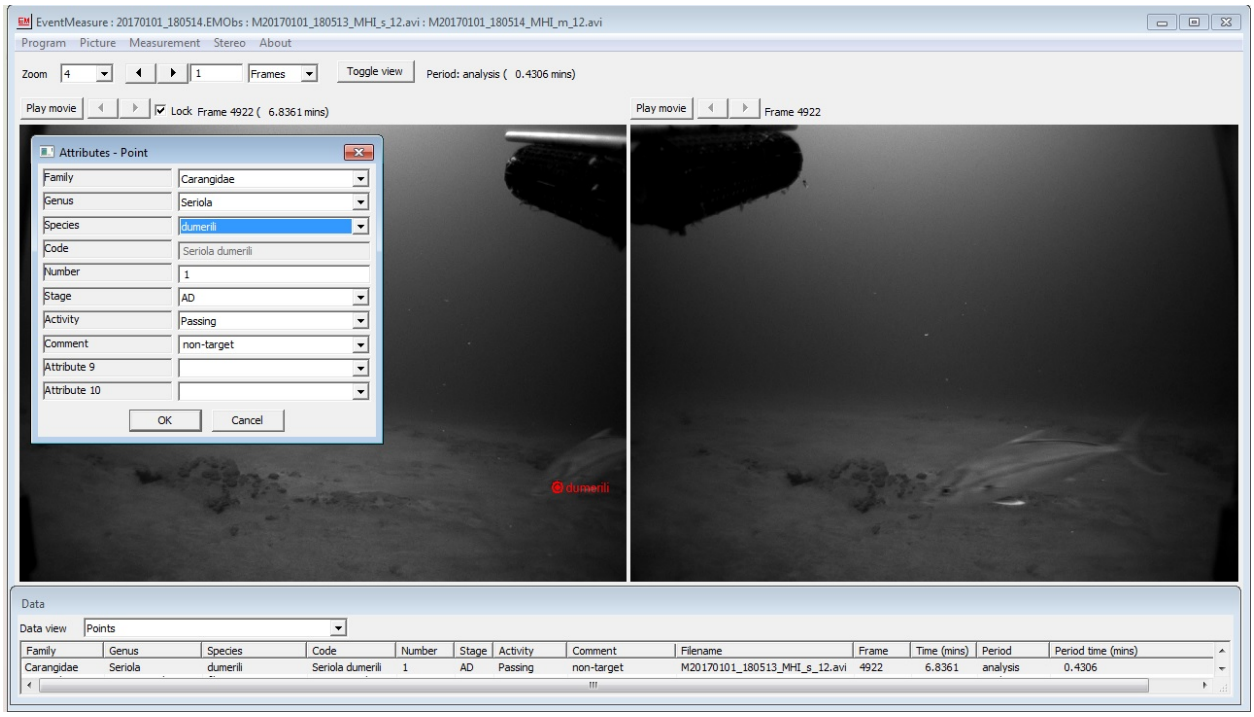

Figure E.9 "Non-target" point observation for *Seriola dumerili*.

Save the .EMObs file regularly or whenever new data points are added.

3. Fish measurement

a. Once all target species have TOFA and MaxN points and all non-target species have points for presence during the 15-minute analysis period, return to the MaxN frame for a target species by double-clicking on the MaxN data point in the data "Points" table.

b. Use the frame step controls to step to a frame where the head and tail of the individual fish being measured are clearly visible. An individual fish may be tracked forward or backward from the frame of MaxN as long as that individual remains in the field of view.

c. Left-click on the tip of the fish's rostrum in the left video then on the tip of the fish's rostrum in the right video (Figure E.10). Left-click on the tip of the fish's tail fork (e.g., the end of the middle tail fin ray) in the left video then on the tip of the fish's tail fork in the right video. Select the appropriate fish ID name with the lowest level of taxonomic certainty, either "Species", "Genus", or "Family" from the drop down menu selection → Enter the fish number for the individual being measured in the "Comment" field (e.g., type "1"for all three measurements of fish individual number 1; type "2"for all three measurements of fish individual number 2; etc.) → OK

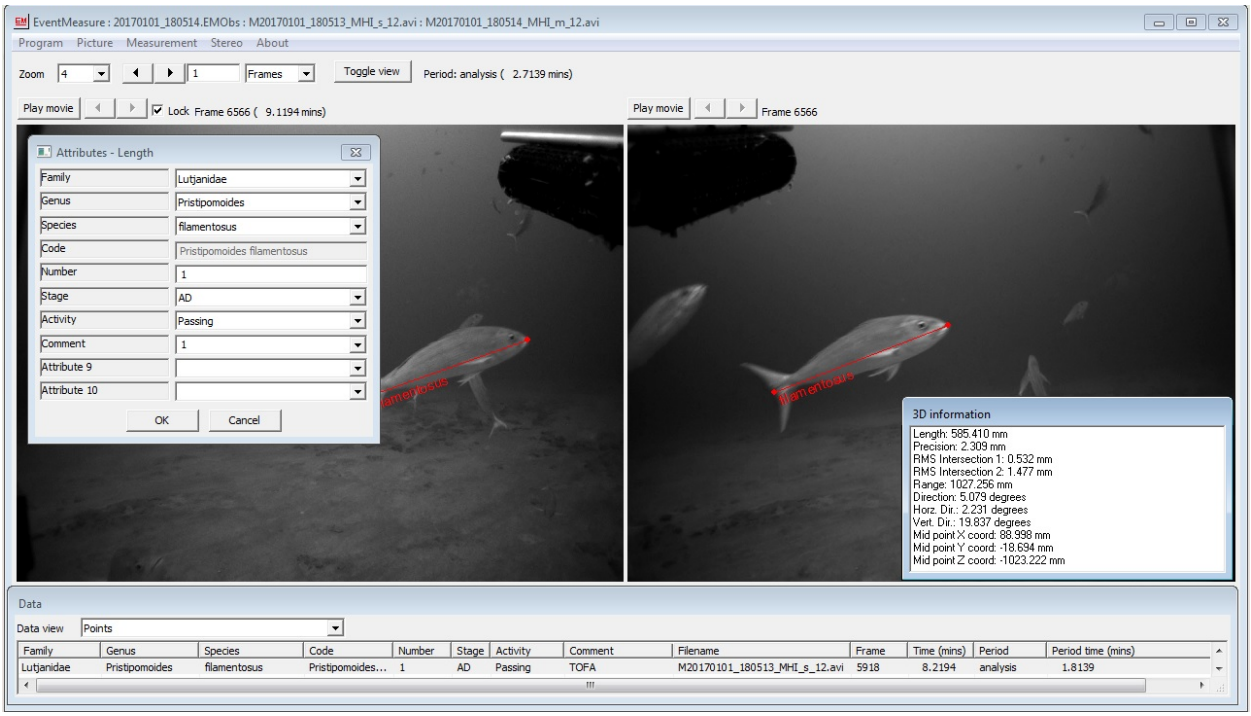

Figure E.10 Measurement of *Pristipomoides filamentosus* for individual number 1.

The fish number in the "Comment" field functions as the identifier for that individual so that the mean length can be calculated from the three replicate measurements made for each individual fish.

Placing a measurement point on one video screen results in an epipolar line automatically appearing on the other video screen; this line can be used as a guide for marking the stereo point corresponding to the initial point that was created; however it is not always accurate, requiring video analysts to use their best judgement. A warning will appear if any of the measurement attributes violate the length rules. If this occurs, check the point placement, camera sync, and/or attempt the measurement from a different video frame

d. Use the frame step controls to move the video forward or backward until the head and tail of the individual fish are clearly visible, and take another measurement. Repeat until three replicate measurements have been taken (2 at minimum).

The "Zoom" function located above the "Play Movie" button can be useful for more accurate point placement. To zoom, select the desired level of magnification; place the cursor over the area of the left video screen to be magnified; hold down the Ctrl key; then move the cursor slightly. Repeat for the right video screen. Adjusting the brightness and contrast may also help to make the outlines of an individual fish more visible.

e. For individual fish which cannot be measured (usually because the head and tail are not simultaneously visible), take a 3-D point for the fish at the frame of MaxN → Double-click on the MaxN data point in the data "Points" table for the target species to be measured → Left-click on the tip of the rostrum/body/tail in the left video then on the

same spot in the right video (use whichever part of the fish is visible in both video screens) → Right-click on the cross mark in the left video screen (Figure E.11) → Select "Add 3D point" → Select the appropriate fish ID name with the lowest level of taxonomic certainty, either "Species", "Genus", or "Family" from the drop down menu selection → Enter the fish number for the individual being measured in the "Comment" field → OK

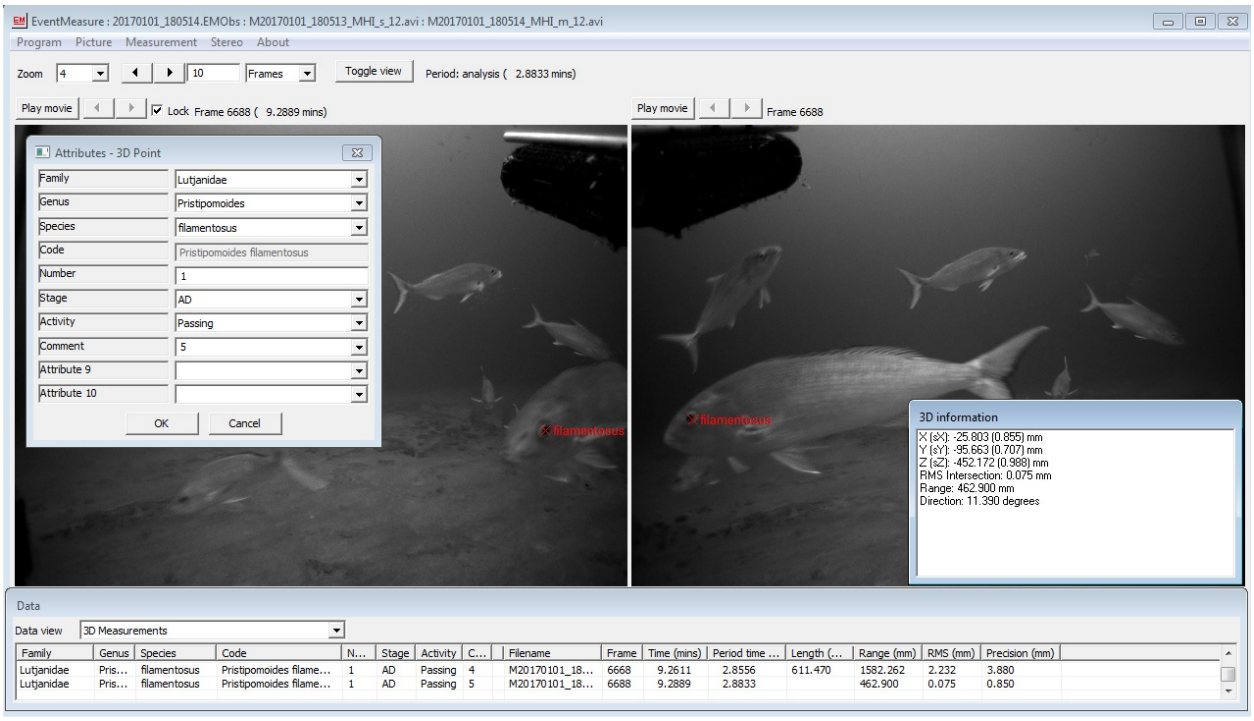

Figure E.11 3-D point measurement of *Pristipomoides filamentosus* for individual number 5.

If a fish that cannot be measured is only visible in the left video screen, place the right screen point in an area approximately near where the fish might be so that a 3-D point can still be generated.

f. View the measurements and 3-D points by selecting "3D Measurements" in the Data view drop down menu of the EventMeasure Data table (Figure E.12).

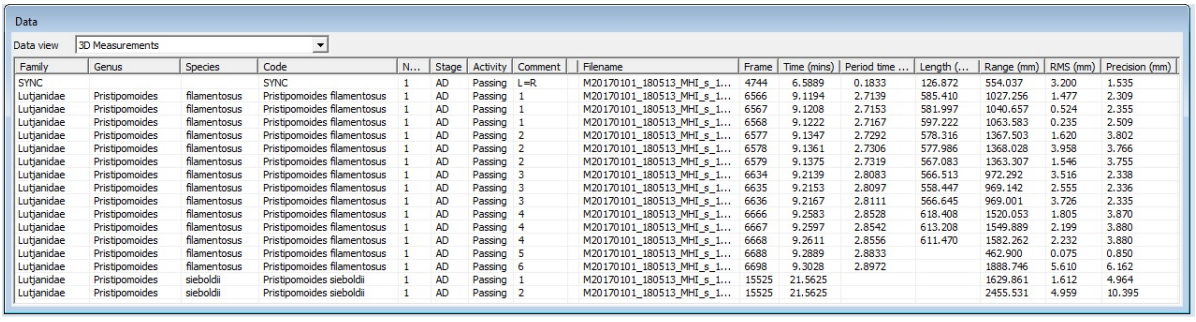

Figure E.12 The 3-D measurements data table containing all measurements and 3-D points.

The maximum difference between replicate length measurements of the same individual fish should be 20 mm or less (depending on desired level of precision). Measurements that fail to meet this criterion should be reviewed for errors or repeated at a better frame.

g. Repeat steps 3a. through 3e. for all target species seen within the 15-minute analysis period; All target species must have a TOFA and MaxN point, and all individual fish for each target species must have a minimum of two replicate measurements taken (three is ideal) or a 3-D point if measurements are not possible. Non-target fish species are identified by a point marking for presence only.

4. Save the EventMeasure data file (.EMObs file)

a. Measurement → Save → Select .EMObs file → Save

Repeat EventMeasure video analysis protocol until all survey videos have been annotated. It is recommended that a portion (e.g., 10-25%) of the total video set be annotated by multiple video analysts to ensure consistency and accuracy of data generated amongst analysts.

5. Concatenate .EMObs files to export survey dataset

a. Set up the export file destination (Program → File concatenation utility → Text file directory → Browse and select appropriate destination folder → OK

b. Enter output file name the same as survey name → Save

c. Select Process to concatenate all .EMObs files.

d. Open the exported data file (.txt file) in the destination folder using Excel to view the final annotated video dataset.